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Three Before-and-After Studies: the Effects of Upgrading the Hot Springs, Lewistown, and Hamilton Wastewater Treatment Facilities on Water Quality

Mark A. Kerr

December 1988

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THREE BEFORE-AND-AFTER STUDIES: THE EFFECTS OF UPGRADING THE HOT SPRINGS, LEWISTOWN, AND HAMILTON WASTEWATER TREATMENT FACILITIES ON WATER QUALITY

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TABLE OF CONTENTS

	Page
TABLE OF CONTENTS	i
LIST OF TABLES	ii
LIST OF FIGURES	v
ABSTRACT	vi
ACKNOWLEDGEMENTS	vii
1. INTRODUCTION	1
2. OBJECTIVE	2
3. STUDY DESIGN	3
4. METHODS	4
4.1 Field Sampling	4
4.2 Water Quality Analysis	4
4.3 Macroinvertebrate Analysis	5
5. HOT SPRINGS CREEK STUDY	9
5.1 Overview	9
5.2 Sampling Locations and Description	10
5.3 Results	10
5.3.1 Water Chemistry	10
5.3.2 Benthic Macroinvertebrates	15
5.4 Discussion	18
6. BIG SPRING CREEK STUDY	24
6.1 Overview	24
6.2 Sampling Locations and Description	25
6.3 Results	25
6.3.1 Water Chemistry	25
6.3.2 Benthic Macroinvertebrates	32
6.3.3 Chlorophyll a Production	43
6.4 Discussion	43
7. BITTERROOT RIVER STUDY	47
7.1 Overview	47
7.2 Sampling Locations and Description	47
7.3 Results	48
7.3.1 Water Chemistry	48
7.3.2 Benthic Macroinvertebrates	54
7.4 Discussion	58
8. CONCLUSIONS	61
9. REFERENCES	62

LIST OF TABLES

Page

1. Criteria for assigning scores to aquatic macroinvertebrate parameters based on their percent comparability to values obtained from the control station (adapted from Plafkin et al 1987)..... 7

2. Criteria for the assessment of biologically significant environmental degradation (from Plafkin et al 1987)..... 8

3. Self-monitoring data for BOD and TSS in the Hot Springs Wastewater Treatment Lagoons influent and effluent, 1983 and 1987..... 12

4. Water quality data for the Hot Springs Wastewater Treatment Lagoons discharge and Hot Springs Creek, 1983 and 1987..... 13

5. Average values for selected water quality variables for the Hot Springs Wastewater Treatment Lagoons discharge and Hot Springs Creek, 1983 and 1987..... 16

6. The number of individuals collected annually (all samples combined) and the percent relative abundance of taxa comprising at least 10% of the macroinvertebrate fauna at stations above or below the Hot Springs Wastewater Treatment Lagoons during 1983 and 1987..... 17

7. Mean values of parameters characterizing macroinvertebrate assemblages above and below the Hot Springs Wastewater Treatment Lagoons during 1983 and 1987 (three samples per year at each station)..... 19

8. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Hot Springs Wastewater Treatment Lagoons during 1983 (one sample per season)..... 19

9. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Hot Springs Wastewater Treatment Lagoons during 1987 (one sample per season)..... 20

10. Average flow in cubic feet per second (cfs), and average loading (AL) in pounds per day and standardized loading (SL) in pounds per day per cfs, Hot Springs Wastewater Treatment Lagoons and Hot Springs Creek..... 21

11. Self-monitoring data for BOD and TSS in Lewistown WWTP influent and effluent, 1983 and 1987..... 27

12. Water quality data for the Lewistown WWTP discharge and Big Spring Creek, 1983 and 1987..... 28

13. Average values for selected water quality variables for the Lewistown WWTP discharge and Big Spring Creek, 1983 and 1987..... 31

14. Mean values of parameters characterizing macroinvertebrate assemblages in Big Spring Creek above and below the Lewistown WWTP during 1983 and 1987 (three kick samples per station).... 33

15. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Lewistown WWTP during 1983 (one kick sample per season)..... 35

16. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Lewistown WWTP during 1987 (one kick sample per season)..... 35

17. Bioassessment scores for stations on Big Spring Creek above and below the Lewistown WWTP during 1987 using 1983 data as controls (one kick sample at each station per season)..... 36

18. Synopsis of statistical analyses (ANOVA and Newman-Keuls tests) of selected parameters characterizing macroinvertebrate assemblages at stations above and below the Lewistown WWTP during 1987 (nine modified Hess samples per station)..... 38

19. Percent relative abundance of numerically dominant macroinvertebrate taxa in traveling-kick samples from Big Spring Creek above and below the Lewistown WWTP during 1983 and 1987 (three samples per station each year combined)..... 40

20. The mean density (number per sample) and percent relative abundance (in parentheses) of macroinvertebrate orders in Big Spring Creek above and below the Lewistown WWTP during 1983 and 1987 (nine modified Hess samples per station each year)..... 42

21. Chlorophyll a accrual and estimated biomass production, Big Spring Creek, 1983 and 1987..... 44

22. Water quality data for the Hamilton WWTP discharge and the Bitterroot River, 1983 and 1986..... 50

23. Average values of selected water quality variables for the Hamilton WWTP discharge and the Bitterroot River, 1983 and 1986..... 52

24. TSS and nutrient loading (pounds per day) to the Bitterroot River from the Hamilton WWTP, 1983 and 1986..... 53

25. Mean values of parameters characterizing macroinvertebrate assemblages above and below the Hamilton WWTP during 1983 and 1986 (three samples per station in 1983 and nine samples per station in 1986)..... 55

26. The mean percent relative abundance of the numerically dominant macroinvertebrate taxa above and below the Hamilton WWTP during 1983 and 1986 (three samples per station in 1983 and nine samples per station in 1986) and for all samples combined..... 55

27. Synopsis of statistical analyses (Newman-Keuls test) of selected parameters characterizing macroinvertebrate assemblages at stations above and below the Hamilton WWTP during 1986..... 57

28. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Hamilton WWTP during 1983 (one sample per season)..... 57

29. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Hamilton WWTP during 1986 (three samples per season)..... 59

LIST OF FIGURES

Page

1. Sampling locations for the Hot Springs Creek before-and-after study..... 11

2. Sampling locations for the Big Spring Creek before-and-after study..... 26

3. Sampling locations for the Bitterroot River before-and-after study..... 49

ABSTRACT

Three "before-and-after" studies were initiated by the State of Montana Water Quality Bureau in 1983 to determine whether the upgrading of wastewater treatment facilities at Hot Springs, Lewistown, and Hamilton resulted in measurable improvements in the water quality and stream biota of the receiving streams (Hot Springs Creek, Big Spring Creek, and the Bitterroot River). Commonly, the effectiveness of improved wastewater treatment has been measured only by the improvement in the quality of the discharge.

Water quality data and benthic macroinvertebrates were collected in spring, summer, and autumn from the receiving waters upstream and downstream of the discharges before upgrading began and twelve to eighteen months after upgrading was completed. Discharges were also sampled at the same time. The limited amount of water quality data precluded a detailed analysis of changes in the variables measured. Analysis was also limited by the availability of flow data or by seasonal and year-to-year variability of streamflows. Macroinvertebrates were analyzed using a bioassessment technique which integrates eight community-level parameters.

Improvement in the quality of the discharges was measured readily. Generally, BOD, TSS, and ammonia concentrations were reduced significantly. Nitrate-nitrite concentrations increased significantly because of more complete treatment of influent organic material and more thorough nitrification of ammonia. Phosphorous concentrations decreased at most 50%. Improvement in the quality of receiving stream waters was less apparent. In Hot Springs Creek, variable streamflows and pollutant loadings from other sources masked effects of the Hot Springs wastewater treatment lagoon discharge. Decreases in pollutant concentrations in Big Spring Creek up to five miles downstream of the Lewistown WWTP discharge were discernable but subtle. In the Bitterroot River, improvement could be detected in the mixing zone but two miles downstream of the Hamilton WWTP discharge nutrient concentrations appeared to increase.

Analysis of macroinvertebrate samples detected, at best, only modest improvement attributable to the upgrading of sewage treatment facilities. Hot Springs Creek and Big Spring Creek appear to be impaired by multiple environmental stresses which largely overwhelmed the improvement attributable to higher quality discharges. The impact of the Hamilton WWTP on the Bitterroot River was slight both before and after upgrading.

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I would like to thank Gary Ingman of the State of Montana Water Quality Bureau and Erich Weber, a former employee of the Bureau, for their participation in the field work. I would like to thank Pamela Brewster, another employee, for typing and editing this report. Finally, I would like to acknowledge the excellent work of Dan McGuire, who identified the aquatic macroinvertebrates, used the integrated bioassessment technique suggested by the U.S. Environmental Protection Agency, and developed very interesting interpretations.

1. INTRODUCTION

Since 1972 nearly 200 million dollars have been spent in Montana under the Construction Grants Program to upgrade wastewater treatment plants so that they conform with secondary treatment standards required by the Federal Clean Water Act (Bahls 1982). The effectiveness of treatment facilities and upgraded wastewater treatment is often judged solely on whether a facility meets its effluent limitations (EPA 1985). Improved instream water quality and uses are two other measures of the effectiveness of upgraded wastewater treatment. In Montana, little or no attempt had been made to document these improvements.

In 1983, the State of Montana Water Quality Bureau (MWQB) initiated three "before-and-after" studies to document improvements in water quality and stream biota resulting from the upgrading of wastewater treatment facilities from primary to secondary treatment. The three wastewater treatment facilities selected for these studies serve the towns of Hot Springs, Lewistown, and Hamilton. These facilities were selected because the ratio of discharge flow to receiving water flow was larger than it was for other facilities scheduled for upgrading at the time. Water and benthic macroinvertebrate samples were collected from the receiving streams in 1983 before upgrading began and in 1986 and 1987 after construction was completed. This report presents the results of sampling conducted on Hot Springs Creek, Big Spring Creek and the Bitterroot River - the receiving waters for the discharges from the Hot Springs, Lewistown and Hamilton wastewater treatment facilities, respectively.

2. OBJECTIVE

The objective of the "before-and-after" studies was to determine whether the upgrading of wastewater treatment facilities at Hot Springs, Lewistown and Hamilton from primary to secondary treatment resulted in a measureable improvement in ambient water quality and stream biota.

3. STUDY DESIGN

Each study required the collection of water quality and benthic macroinvertebrate samples before upgrading began and after upgrading was completed. Samples were collected 12 to 18 months after upgrading to allow for fine tuning of treatment plant operations and for complete recovery of the aquatic ecosystem. Monitoring locations included one control site upstream of the discharge, one station just below the discharge, and one or two stations further downstream. Wastewater discharges were also sampled. Sampling was conducted in early spring, late summer, and mid-autumn.

Upgrading from primary to secondary treatment significantly reduces concentrations of total suspended solids (TSS) and biochemical oxygen demand (BOD) in the effluent. Secondary treatment may also reduce potentially toxic concentrations of ammonia through nitrification. There is often no significant reduction in concentrations of nutrients (phosphorous and inorganic nitrogen) that promote algae growth (Bahls 1982). Water samples were analyzed for nutrients (ammonia and nitrate-nitrite, orthophosphorous, and total phosphorous), temperature, pH, total suspended solids (TSS), turbidity, and specific conductance. Total inorganic nitrogen (TIN) was calculated as the sum of the nitrate-nitrite and ammonia concentrations. Streamflow and discharge flow were measured where possible. Self-monitoring data for BOD and TSS which were collected by treatment plant operators were also evaluated.

Several biotic communities were analyzed. Benthic macroinvertebrates were collected because the structure and composition of this community may respond to a change in the quality of a discharge. They may also provide a "truer" indication of "average" ambient water quality than does a limited water sampling program. The growth of periphyton on artificial substrates in Big Spring Creek was estimated from chlorophyll a accrual rates to determine whether changes in nutrient concentrations in the Lewistown WWTP effluent affected primary production.

4. METHODS

4.1 Field Sampling

Water temperature was measured with a mercury field thermometer having gradations of 1°C and a resolution of 0.1°C. Streamflow was measured with a Marsh-McBirney Model 2100 Water Current Meter. Wastewater discharges were either gaged or determined from in-plant flow totalizers or weirs and rating tables.

Benthic macroinvertebrates were collected with a modified Hess sampler for quantitative analysis, or with a D-net using a traveling kick or unit effort kick method for qualitative analysis. Each study differed in the method used and number of replicates collected.

Artificial substrates for measuring primary productivity (Big Spring Creek only) consisted of eight standard microscope slides held in commercial plastic carriages (Periphytometer II) which were anchored to the substrate. Exposure time was approximately three weeks. Slides were then stored frozen until chlorophyll was extracted and analyzed.

Water samples were collected in new polyethylene bottles and preserved following guidelines of the U.S. Environmental Protection Agency (U.S. EPA 1988).

4.2 Water Quality Analysis

The analysis of water quality data was limited by the small number of samples which were collected. At most, three samples were collected at each site before and after upgrading in the Hot Springs Creek and Bitterroot River studies. Five or six samples were collected at each site in each phase of the Big Spring Creek study. The paucity of data precluded more than a non-statistical comparison of yearly averages and ranges of concentrations.

"Average" concentrations were practically meaningless in Hot Springs Creek because of extreme seasonal and annual variation in flow, and effects of other pollutant sources. Concentrations of most variables fluctuated wildly, with little

or no relationship to flow. An attempt was made to characterize "average" water quality by calculating a standardized loading. The standardized loading describes the weight of a pollutant in pounds per day per cubic foot per second (cfs) of water. It was determined by calculating the total loading of a pollutant (in pounds per day) for all sampling episodes in one year and dividing it by the total flow for that year. The standardized loading is, therefore, nothing more than a loading, in pounds per cfs, calculated using a flow-weighted pollutant concentration. The same result would be achieved by physically compositing one second of flow from each sampling episode, measuring the pollutant concentration in mg/l, and calculating the resulting load per cfs.

4.3 Macroinvertebrate Analysis

Macroinvertebrate data were evaluated using an integrated analysis technique adapted from the Rapid Bioassessment Protocols under development for the U.S. Environmental Protection Agency (Plafkin et al. 1987). Eight community-level parameters were used to provide a composite, integrated evaluation of biologically significant degradation. These parameters were:

1. total macroinvertebrate abundance
2. taxa richness
3. Shannon diversity
4. biotic index
5. EPT richness (number of distinct taxa in the orders Ephemeroptera, Plecoptera, and Trichoptera)
6. ratio of EPT to Chironomidae (relative abundance of Ephemeroptera, Plecoptera, and Trichoptera to Chironomidae)
7. Percent Community Similarity (PCS) index

8a. Percent Relative Abundance (PRA) of the dominant taxa (Hot Springs Creek study only)

8b. ratio of scrapers to filter feeders (relative abundance of functional feeding groups, Bitterroot River and Big Spring Creek studies only)

These parameters provide a wide range of sensitivity to water quality degradation. Each parameter provides a slightly different measure of the benthic community with the parameters' responses varying according to the type and severity of pollution. The sensitivity of some parameters overlap; this redundancy minimizes the consequences of an aberrant value for one parameter. Integrating individual parameters into a composite evaluation increases the reliability of conclusions while enhancing the sensitivity of the evaluation to a wider range of pollution effects.

For each sampling period and station, all parameters but one were assigned scores based on their similarity to the values at the control station (Table 1). The percent relative abundance of the dominant taxa was assigned a score based on the actual percent contribution, not percent comparability to the reference station. The sum of the scores assigned to the eight parameters provides an integrated evaluation of biologically significant degradation at each site (Table 2).

In studies where replicate samples were collected (Bitterroot River and Big Spring Creek), statistical analyses were used to test for differences in the community-level parameters among sites and seasons. These tests included a two-way Analysis of Variance (Sorkal and Rohlf 1981) and the Newman-Keuls test (Zar 1974).

Where appropriate, total macroinvertebrate abundance, ordinal densities, ordinal relative abundances, the relative abundance of numerically dominant taxa and presence/absence data were compared among stations and between years.

Table 1. Criteria for assigning scores to aquatic macroinvertebrate parameters based on their percent comparability to values obtained from the control station (adapted from Plafkin et al 1987).

Parameter	Scoring Criteria[1]			
	6	4	2	0
Abundance[2]	50-150%	35-50% or 150-200%	20-35% or 200-250%	<20% or <250%
Taxa richness	>80%	60-80%	40-60%	<40%
Shannon diversity	>90%	80-90%	70-80%	<70%
Biotic index	>90%	80-90%	70-80%	<70%
EPT richness	>90%	80-90%	70-80%	<70%
Ratio of EPT to Chironomidae	>75%	50-75%	25-50%	<25%
Percent Community Similarity (PCS) index	>80%	60-80%	40-60%	<40%
Percent Relative Abundance (PRA) of dominant taxa[3]	<20%	25-35%	35-45%	>45%
Ratio of scrapers to filterers[4]	>50%	35-50%	20-35%	<20%

1 Values falling at break points for scoring categories may be assigned intermediate scores.

2 Total macroinvertebrate abundance substantially higher (>150%) or substantially lower (<35%) than values at the control station is indicative of environmental degradation.

3 Hot Springs Creek study only.

4 Big Spring Creek and Bitterroot River studies only.

Table 2. Criteria for the assessment of biologically significant environmental degradation (from Plafkin et al 1987).

Cumulative Score	Classification
40-48	Non-impaired
26-38	Slightly impaired
10-24	Moderately impaired
<8	Severely impaired

5. HOT SPRINGS CREEK STUDY

5.1 Overview

The town of Hot Springs is located approximately ninety miles northwest of Missoula. It is situated on the southeast edge of the Cabinet Mountains in the drainage of the Little Bitterroot River.

The new wastewater treatment facility replaces an activated sludge plant built in 1954. This plant had a design flow of approximately 100,000 gallons per day (gpd) and served approximately 600 persons. In the late 1970's, rehabilitation of the town's sewer lines was attempted in order to reduce infiltration and inflow, but plant inflow actually increased after the work was completed. By 1980, approximately 80% of the flow to the plant was infiltration, and bypasses of raw sewage to Hot Springs Creek became common. The plant was also unable to meet effluent limits because of hydraulic overload which reduced detention time throughout the treatment process. BOD concentrations exceeded limits approximately 10 percent of the time and TSS exceeded limits 34 percent of the time (Storch Corporation/Engineers 1982).

Construction of the new wastewater treatment facility began early in 1985 and was substantially complete by mid-1986. The facility, which has a design flow of 237,000 gpd, consists of two aerated primary treatment cells and one aerated secondary treatment cell, followed by chlorine disinfection. Detention time is approximately 25 days.

Hot Springs Creek is the receiving stream for the town's wastewater discharge. It originates in the Cabinet Mountains west of town, and joins the Little Bitterroot River approximately five miles east of town. It is the only major creek in the area. The stream is classified A-Closed (protective of public surface water supplies) upstream of the Hot Springs water supply intake and C-3 from the Hot Springs water supply intake to the Little Bitterroot River, including the reach downstream of and just upstream from the Hot Springs lagoon discharge. Waters classified C-3 are suitable for recreation,

and growth and propagation of warm water aquatic life. They are marginal for potable, agricultural, and industrial uses.

Within the immediate area of the wastewater treatment lagoon, water quality in Hot Springs Creek is strongly influenced by soil structure, soil composition, and land use practices. The dominant soil types are silts and clays deposited as glacial lake sediments. These soils are highly erosive and very susceptible to undercutting and slumping. Damming and ponding by beavers, which is quite common, alter natural stream flows and divert much of the stream onto adjacent agricultural fields. This sheet flow reenters the main creek channel at diffuse points downstream of the wastewater treatment facility. These influences are the primary determinants of water quality in Hot Springs Creek and may limit the discernment of impacts of the wastewater discharge.

5.2 Sampling Locations and Description

Three monitoring stations were located on Hot Springs Creek. The control (HS01) was located approximately one-quarter mile upstream of the discharge (HS02). One station (HS03) was located approximately one hundred yards downstream of the discharge. Another station (HS04) was located, approximately two miles downstream of the discharge (Figure 1).

Several stations had to be relocated after upgrading because the effluent outfall was moved approximately three-quarters of a mile downstream of its original location. In 1987, the control site was located just downstream of 1983's station HS03. The location of HS04 was unchanged.

5.3 Results

5.3.1 Water Chemistry

Self-monitoring data for BOD and TSS (Table 3) demonstrate an improvement in the quality of the wastewater discharge. The average monthly BOD concentration decreased 50% The average monthly TSS concentration decreased approximately 25%. TSS concentrations in effluent samples collected by MWQB before and after upgrading (Table 4) were similar to

Figure 1. Sampling locations for the Hot Springs Creek before-and-after study.

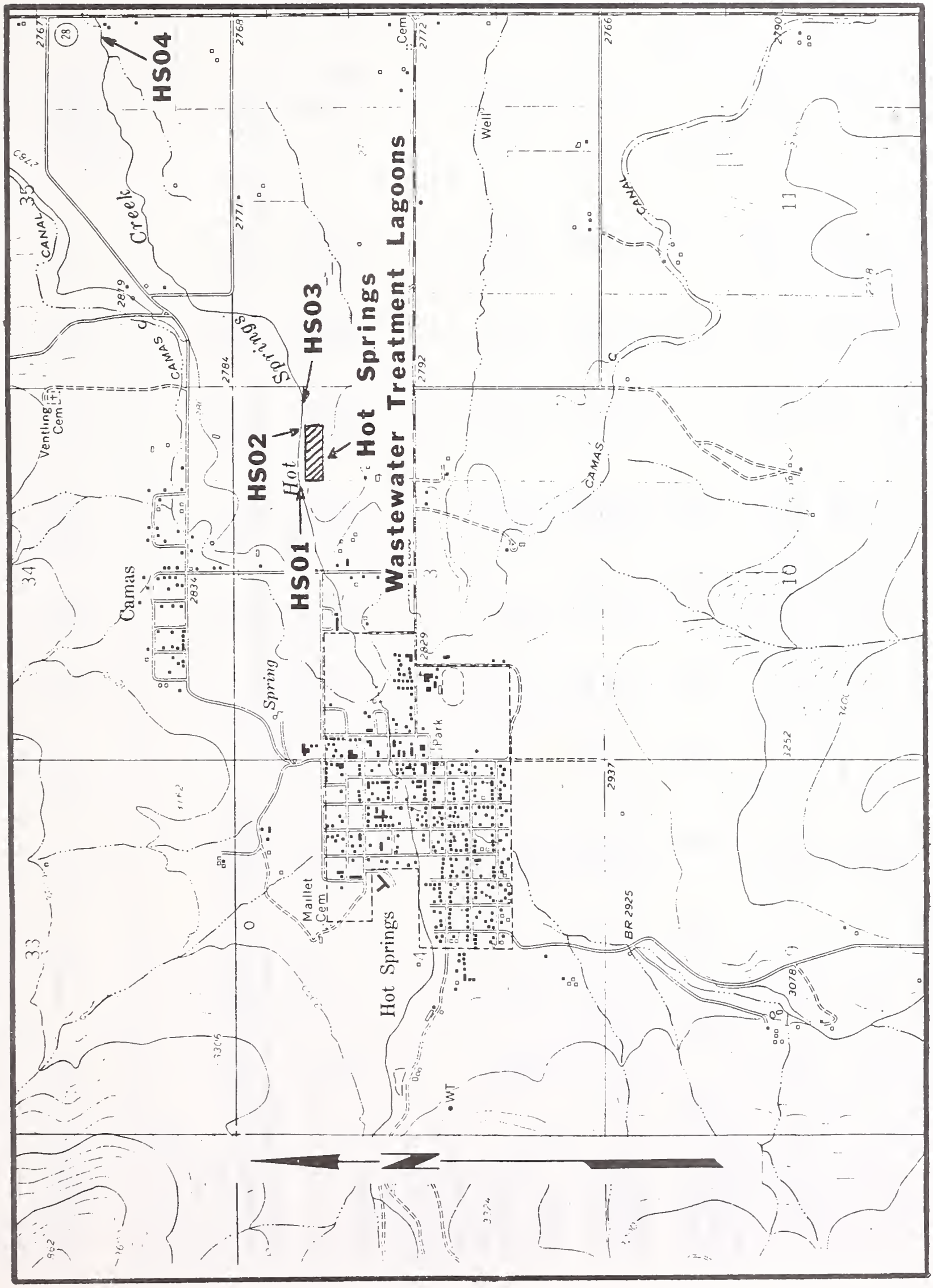

Table 3. Self-monitoring data for BOD and TSS in the Hot Springs Wastewater Treatment Lagoons influent and effluent, 1983 and 1987.*

Year and Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
1983													
BOD, mg/L													
Influent	90	143	96	66	27	36	119	102	---	36	44	50	74
Effluent	29	12	20	39	23	6	28	33	---	25	33	41	28
TSS, mg/L													
Influent	66	276	84	30	25	80	56	180	---	56	21	35	83
Effluent	17	28	30	42	18	16	12	47	---	38	16	35	27
1987													
BOD, mg/L													
Influent	---	---	60	88	---	---	---	---	---	---	---	---	74
Effluent	9	---	15	6	---	---	---	---	29	10	---	---	14
TSS, mg/L													
Influent	---	---	96	66	---	---	---	---	---	---	---	---	81
Effluent	1	---	23	9	---	---	---	---	64	4	---	---	20

* Data from September and October, 1987 are monthly average concentrations. All other data are monthly maximum concentrations. Influent sampling was discontinued in mid-1987.

Table 4. Water quality data for the Hot Springs Wastewater Treatment Lagoons discharge and Hot Springs Creek, 1983 and 1987.

Sampling Location and Date	Flow cfs	Temperature °C	Lab pH	Turbidity ntu	TSS mg/L	NH_3 mg/L-N	NO_2+NO_3 mg/L-N	TIN mg/L-N	Ortho-P mg/L	Total-P mg/L	Specific Conductance umhos at 25°C
Hot Springs Creek upstream of discharge (HS01)											
March 1983	4.20	5.0	7.91	8	2.6	0.01	<0.01	0.01	0.017	0.02	112
August 1983	2.85	22.0	7.73	23	25.1	0.02	0.02	0.04	0.059	0.07	136
November 1983	0.68	4.0	7.80	23	20.5	0.01	0.03	0.04	0.029	0.03	190
April 1987	11.4	9.8	6.98	15	17.7	<.01	<.01	0.01	0.021	0.036	55
August 1987	2.56	16.7	7.63	9	6.1	0.08	0.02	0.10	0.025	0.040	145
November 1987	0.05	---	7.63	16	8.3	0.02	0.20	0.22	0.099	0.107	277
Hot Springs Wastewater Treatment Lagoon discharge (HS02)											
March 1983	0.34	8.0	7.09	25	59.3	6.0	0.24	6.24	1.70	2.70	398
August 1983	0.34	19.5	7.25	8	19.4	8.8	0.26	9.06	2.00	2.60	392
November 1983	0.24	13.0	6.90	18	26.8	8.2	0.07	8.27	1.69	3.50	376
April 1987	0.51	12.1	7.74	6	15.8	1.92	0.66	2.58	1.30	1.44	312
August 1987	0.07	18.2	8.97	30	68.1	0.15	1.35	1.50	2.12	2.34	362
November 1987	0.03	---	7.48	6	4.5	7.93	0.93	8.86	3.73	3.88	506
Hot Springs Creek just downstream of discharge (HS03)											
March 1983	4.54	4.0	7.48	10	*8.4	0.46	0.04	0.50	0.15	0.23	118
August 1983	3.19	22.0	7.43	21	26.4	1.2	0.07	1.27	0.32	0.40	173
November 1983	0.92	7.0	7.09	18	8.3	2.1	0.06	2.16	0.46	0.63	233
April 1987	11.9	8.7	7.18	16	13.7	0.06	0.02	0.08	0.062	0.087	61
August 1987	2.63	15.6	7.57	9	11.2	0.04	0.07	0.11	0.129	0.156	158
November 1987	0.08	6.5	7.33	10	5.1	5.66	0.83	6.49	2.59	2.96	446

* TSS concentration was calculated using less than recommended volume of water and is subject to significantly increased error.

Table 4. Continued

Sampling Location and Date	Flow cfs	Temperature °C	Lab pH	Turbidity ntu	TSS mg/L	NH_3 mg/L-N	NO_2+NO_3 mg/L	TIN mg/L-N	Ortho-P mg/L	Total-P mg/L	Specific Conductance umhos at 25°C
Hot Springs Creek at Highway 25 Crossing (HS04)											
March 1983	5.10	3.5	7.75	17	24.3	0.13	0.12	0.25	0.10	0.14	112
August 1983	4.02	20.5	7.31	25	30.7	0.14	0.50	0.64	0.49	0.56	205
November 1983	1.02	4.0	7.25	26	25.8	0.94	1.00	1.94	0.38	0.38	231
April 1987	15.0	13.8	7.14	41	62.2	<.01	<.01	0.01	0.094	0.13	62
August 1987	2.98	20.2	7.55	32	38.5	0.39	0.01	0.40	0.147	0.173	165
November 1987	0.09	---	7.96	37	30.1	1.71	1.76	3.47	1.93	1.98	416

concentrations reported by the permittee. High concentrations of TSS in the effluent of lagoon treatment systems are often caused by heavy blooms of algae which thrive in these nutrient-rich environments.

The average ammonia concentration decreased 57% in the effluent after upgrading, from 7.7 mg/l to 3.3 mg/l, but the ranges of concentrations indicate that ammonia may still approach levels observed before upgrading. The average nitrate-nitrite concentration increased from 0.19 mg/l to 0.98 mg/l. The average orthophosphorous concentration increased from 1.80 mg/l to 2.38 mg/l, and the average total phosphorus concentration decreased from 2.93 mg/l to 2.55 mg/l. However, the ranges of phosphorous concentrations suggest that there was little if any change after upgrading.

Water quality in Hot Springs Creek was difficult to interpret because it was so variable. Generally, it was more variable in 1987 than in 1983, although for most water quality variables two of the three concentrations measured in 1987 were within the ranges observed in 1983 (Table 4). Because the third concentration was much higher, average concentrations of ammonia, nitrate-nitrite, TIN, orthophosphorous and total phosphorous were greater in 1987 than in 1983 at all stream locations (Table 5). In most instances, this third concentration was measured in November, 1987 when streamflow was extremely low. Average turbidity and TSS were lower in 1987 at HS01 and HS03, but higher at HS04.

5.3.2 Benthic Macroinvertebrates

One benthic macroinvertebrate sample was collected at each stream location in the spring, summer, and autumn before and after upgrading, using the traveling kick method. Taxa comprising at least 10% of the macroinvertebrate fauna at stations above or below the discharge are listed in Table 6. Community composition at HS03 was highly variable between years (Table 6) and among sampling dates (unpublished data). Dramatic changes in the abundance of dominant taxa indicate frequent

Table 5. Average values for selected water quality variables for the Hot Springs Wastewater Treatment Lagoons discharge and Hot Springs Creek, 1983 and 1987.

Sampling Location and Year		Flow cfs	Turbidity ntu	TSS mg/L	NH_3 mg/L-N	NO_2+NO_3 mg/L-N	TIN mg/L-N	Ortho-P mg/L	Total-P mg/L	Specific Conductance umhos at 25°C
HS01	1983	2.58	18	16.1	0.013	0.018	0.031	0.035	0.040	146
	1987	4.67	13	10.7	0.035	0.075	0.110	0.048	0.061	159
HS02	1983	0.31	17	35.2	7.67	0.19	7.86	1.80	2.93	389
	1987	0.20	20	29.5	3.33	0.98	4.31	2.38	2.55	393
HS03	1983	2.88	16	14.4	1.25	0.06	1.31	0.31	0.420	175
	1987	4.87	12	10.0	1.92	0.31	2.23	0.93	1.068	222
HS04	1983	3.38	23	26.9	0.40	0.54	0.94	0.323	0.360	183
	1987	6.02	37	43.6	0.70	0.59	1.29	0.724	0.761	214

Table 6. The number of individuals collected annually (all samples combined) and the percent relative abundance of taxa comprising at least 10% of the macroinvertebrate fauna at stations above or below the Hot Springs Wastewater Treatment Lagoons during 1983 and 1987.

		1 9 8 3				1 9 8 7			
Taxon	Station:	Total Number	HS01	HS03	HS04	Total Number	HS01	HS03	HS04
Tubificidae*		0				2929	13%	28%	31%
Simulium spp.		1238	2%	<1%	45%	1640	9%	19%	10%
Micropsectra sp.		274	5%	<1%	5%	2337	13%	34%	3%
Cheumatopsyche sp.		1156	34%	<1%	11%	1354	30%	2%	9%
Hyallela azteca		560	14%	2%	6%	1886	14%	5%	33%
Gammarus sp.		2154	10%	63%	6%	102	<1%	<1%	3%
Diamesa sp.		806	3%	9%	18%	171	3%	<1%	2%
Prostoia besametsa		340	10%	<1%	0%	207	5%	1%	0%

* Tubificidae were not identified or enumerated in 1983 samples.

environmental perturbations.

Most community-level parameters exhibited relatively low mean values characteristic of a moderately impaired environment (Table 7). Some parameters clearly improved from 1983 to 1987 (taxa richness, Shannon diversity, PRA of dominant taxa, PCS index). Cumulative scores (Tables 8 and 9) indicate improvement at downstream stations each season in 1987. HS03 was moderately impaired two of three seasons both years, severely impaired in November 1983 and slightly impaired in April 1987. The severe impairment in November 1983 may have resulted from a spill into a sewer of 1800 gallons of heating oil, which was recovered from the creek between HS02 and HS03. HS04 was moderately impaired two seasons in 1983 (slightly impaired the third season) and slightly impaired two seasons in 1987 (moderately impaired the third). In both years, conditions at HS04 appeared to improve from spring to autumn (McGuire 1988a).

5.4 Discussion

The improvement in the quality of the Hot Springs wastewater discharge is evident in the reduced concentrations of BOD and TSS. Phosphorous concentrations in 1987 were comparable to those measured in 1983. Ammonia appears to have decreased in the effluent, although the concentration measured in November 1987 is almost as high as concentrations measured before upgrading. Higher nitrate-nitrite concentrations were probably due to nitrification of ammonia. It is likely that violations of BOD and TSS limits, as well as bypasses of raw sewage to Hot Springs Creek, have been eliminated. Pollutant loadings to Hot Springs Creek have also decreased dramatically (Table 10).

The variability of pollutant concentrations and streamflow makes interpretation of instream water quality data difficult. Average concentrations for most variables tended to be higher in 1987 than in 1983, often by two or three fold. The very poor water quality and abnormally low flows which occurred in November 1987 skewed average concentrations considerably. Standardized water quality (pounds per day per cfs) was very

Table 7. Mean values of parameters characterizing macroinvertebrate assemblages above and below the Hot Springs WWTP during 1983 and 1987 (three samples per year at each station).

	1983			1987		
PARAMETER Station:	HS01	HS03	HS04	HS01	HS03	HS04
Abundance	840	920	900	1,060	1770	1,150
Taxa richness	30	18	20	28	25	27
Shannon diversity	2.7	1.9*	2.6	2.9	2.6	3.0
Biotic index (0-10)	5.1	4.9*	5.6	5.9	6.5	7.0
EPT richness	6	3	2	3	2	2
EPT/C ratio	18.0	0.02	3.18	2.72	0.10	1.71
%RA dominant taxon	48	60*	38	33	37	29
PCS index	-	24*	40	-	44	46

* based on March and August data only.

Table 8. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Hot Springs WWTP during 1983 (one sample per date).

Station:	HS03			HS04		
PARAMETER	Mar.	Aug.	Nov.	Mar.	Aug.	Nov.
Abundance	6	4	2	4	0	4
Taxa richness	4	4	0	2	4	6
Shannon diversity	4	0	0	0	6	6
Biotic index	3	6	0	3	6	6
EPT richness	2	0	0	0	0	6
EPT/C ratio	0	0	0	2	0	0
PCS index	0	0	0	0	0	2
%RA dominant taxon	4	0	0	0	3	6
Total score	23	14	2	11	21	36

Table 9. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Hot Springs Wastewater Treatment Lagoons during 1987 (one sample per season).

Station:	HS03			HS04		
Parameter	Apr.	Aug.	Nov.	Apr.	Aug.	Nov.
Abundance	6	5	2	4	6	4
Taxa richness	4	6	2	4	6	6
Shannon diversity	4	6	4	4	6	6
Biotic index	4	4	6	2	5	4
EPT richness	0	0	6	0	0	6
EPT/C ratio	2	0	0	0	4	6
PCS index	2	0	2	0	2	2
PRA dominant taxa	5	2	0	6	4	2
Total score	27	23	22	20	35	36

Table 10. Average flow in cubic feet per second (cfs), and average loading (AL) in pounds per day and standardized loading (SL) in pounds per day per cfs, Hot Springs Wastewater Treatment Lagoons and Hot Springs Creek.

Sampling Location and Year	Flow cfs	TSS AL	TSS SL	NH_3-N AL	NH_3-N SL	NO_2+NO_3-N AL	NO_2+NO_3-N SL	TIN AL	TIN SL	Ortho-P AL	Ortho-P SL	Total-P AL	Total-P SL
HS01													
1983	2.58	173.2	67.1	0.19	0.07	0.18	0.07	0.37	0.14	0.47	0.18	0.55	0.21
1987	4.67	391.3	83.8	0.47	0.10	0.21	0.04	0.68	0.15	0.55	0.12	0.93	0.20
HS02													
1983	0.31	59.7	192.6	12.58	40.58	0.34	1.10	12.92	41.68	2.99	9.64	4.75	15.32
1987	0.20	23.3	116.5	2.21	11.05	0.82	4.10	3.03	15.15	1.66	8.30	1.82	9.10
HS03													
1983	2.88	233.6	81.1	14.10	4.90	0.83	0.29	14.93	5.18	3.82	1.33	5.21	1.81
1987	4.87	346.6	71.2	2.29	0.47	0.88	0.18	2.60	0.53	2.31	0.47	3.02	0.62
HS04													
1983	3.38	491.7	145.5	3.92	1.16	6.54	1.93	10.46	3.09	5.15	1.52	6.02	1.78
1987	6.02	1887.3	313.5	2.50	0.41	0.47	0.08	2.97	0.49	3.63	0.60	4.75	0.79

similar both years at HS01. At HS03, standardized loadings of ammonia and TIN in 1987 were 10% of 1983 loadings. Orthophosphorous and total phosphorous were two-thirds lower. Similar improvement occurred at HS04 for all parameters except TSS, which more than doubled.

A number of other influences affect water quality in Hot Springs Creek. Highly erodible silts and clays derived from glacial lake sediments form much of the creekbed and probably result in high natural background levels of TSS and turbidity. Also, beaver damming is very common, altering natural streamflows and nutrient assimilation and cycling processes. This activity also diverts much of the streamflow onto adjacent agricultural land. This flow reenters the creek at diffuse points downstream, carrying significant amounts of sediment and nutrients. Average TSS and nitrate-nitrite concentrations were higher at HS04 than at HS03 both years. Standardized loads of TSS clearly increased both years between stations. Nutrient loadings were more variable.

The integrated analysis of macroinvertebrate samples indicated that, overall, the environmental integrity of Hot Springs Creek improved only moderately. Biotic index values at HS03 and HS04 in 1987 (6.5 and 7.0, respectively) indicated fairly poor water quality and significant organic pollution. Macroinvertebrate assemblages in both years were characteristic of a moderately impaired environment and multiple stresses. The apparent improvement documented between 1983 and 1987 at downstream stations is attributable, in part, to degradation of the control site. At HS01, sharp declines in taxa richness, Shannon diversity, and EPT richness from spring to summer was possibly due to chlorine toxicity (a total chlorine concentration of 0.06 mg/l was measured in the field during the summer of both years). Significantly lower ammonia and BOD concentrations in the effluent, as well as the elimination of raw sewage bypasses to the creek, may have also contributed to the apparent improvement in macroinvertebrate assemblages.

Variability in community composition at HS03 both years

indicated frequent environmental perturbations. Stresses on the biological community at this site caused by chlorine, ammonia, and nutrient loading were at least additive and probably multiplicative. Improvement observed at HS04 from spring to autumn both years may be attributable to winter nitrite toxicity from ammonia nitrification. Amelioration of toxic conditions followed by biological recovery could have then occurred in summer and autumn (McGuire 1988a).

6. BIG SPRING CREEK STUDY

6.1 Overview

The town of Lewistown is located in Fergus County approximately 100 miles southeast of Great Falls. It is situated in rolling foothill country in a mountainous area of the central part of the state.

Lewistown's original wastewater treatment plant was built in 1939. The plant was expanded in 1965 and provided primary sedimentation and disinfection by chlorination before discharging to Big Spring Creek. At the time of expansion, the collection system outfall line was replaced to exclude large volumes of infiltration. This plant provided adequate primary treatment during dry weather, but peak wet weather flows exceeded the 4 million gallons per day capacity of the system, requiring a partial bypass of raw wastewater to the chlorine contact basin.

Further upgrading of the facility occurred and was completed in August, 1986. Secondary treatment is provided by rotating biological contactors and disinfection by ultraviolet radiation before wastewater is discharged to Big Spring Creek. The primary clarifiers and anaerobic digesters from the previously constructed facilities were rehabilitated and utilized in the 1986 upgrade. The plant currently serves an estimated 7100 persons and is designed for an average daily flow of 2.83 million gallons and a peak hourly flow of 9.0 mgd. Sewer lines were rehabilitated in 1979, and infiltration was reduced by approximately 0.70 mgd, on average, and by 0.95 mgd at peak flows. However, infiltration and inflow still contribute significantly to the plant flow (HKM Associates 1981).

Big Spring Creek is the receiving stream for the Lewistown WWTP discharge. The creek's source is a spring located about six miles southeast of Lewistown. This water is believed to originate as subsurface drainage from carbonate rocks in the Big Snowy Mountains. A fish hatchery is located near the spring. Big Spring Creek flows northwest from its source, through the city of Lewistown, to its confluence with the Judith River.

Big Spring Creek was described as a "hard, calcium-bicarbonate" type water (MDHES 1975), reflecting its origins in the carbonate terrains of the Big Snowy Mountains. The creek experiences less variability in water temperature, discharge, and concentrations of most chemical constituents than many surface streams because of the relatively constant nature of groundwater recharge. Big Spring Creek is classified B-2 from a point upstream of the Lewistown WWTP to the Judith River. Waters classified B-2 are suitable for potable, recreational, agricultural, and industrial uses, and for growth and marginal propagation of cold water aquatic life. The stream is considered a "blue-ribbon" trout stream, and supports populations of brown and rainbow trout. A periphyton analysis of the stream performed in 1974 reported the trophic status to be enriched, probably due to organic and nutrient loading from the Lewistown WWTP, the fish hatchery, and septic tank systems (MDHES 1975).

6.2 Sampling Locations and Description

Figure 2 shows locations sampled upstream and downstream of the WWTP discharge (SC02). The station upstream of the discharge was the control (SC01). Station SC03 was located approximately two hundred yards downstream of the wastewater discharge. Station SC04 was located approximately two miles downstream of the discharge, and station SC05 was located approximately five miles downstream.

6.3 Results

6.3.1 Water Chemistry

Self-monitoring data (Table 11) indicate that the monthly average concentration of effluent BOD decreased 77%, from 38 mg/l to 13 mg/l, after upgrading. TSS decreased 45%, from 20 mg/l to 11 mg/l. Monitoring conducted by MWQB (Tables 12 and 13) also documented a decrease in TSS and, in addition, turbidity (73%).

The greatest improvement occurred in ammonia. The average concentration decreased 88% from 5.0 mg/l in 1983 to 0.6

Figure 2. Sampling locations for the Big Spring Creek before-and after study.

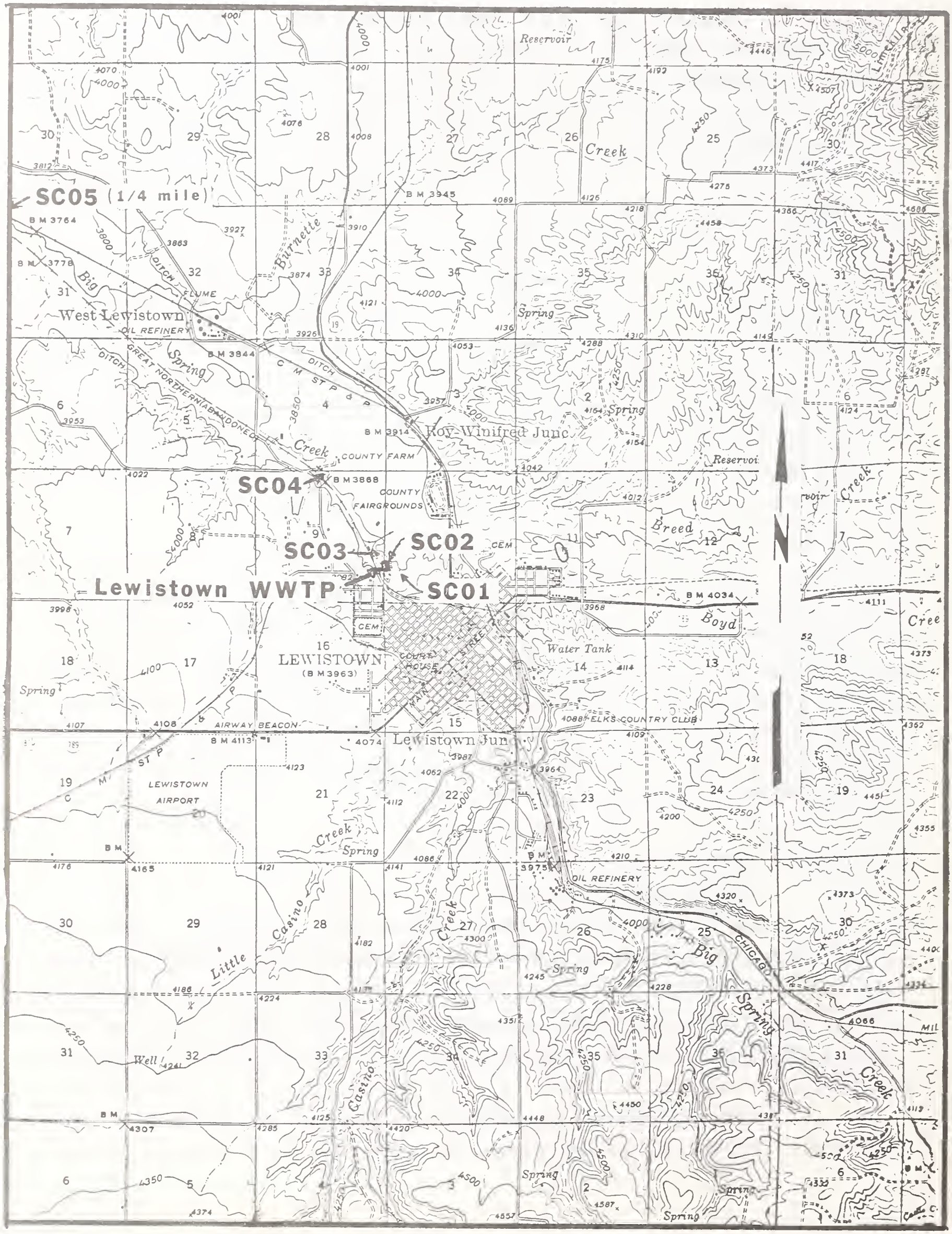

Table 11. Self-monitoring data for BOD and TSS in the Lewistown WWTP influent and effluent, 1983 and 1987.*

Year and Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
1983													
BOD, mg/L													
Influent	71	113	105	127	70	82	78	73	88	96	83	93	90
Effluent	28	39	41	46	41	40	34	36	39	36	40	38	38
TSS, mg/L													
Influent	60	64	62	120	66	78	61	49	65	76	68	88	71
Effluent	14	17	18	23	23	22	24	18	19	19	25	21	20
1987													
BOD, mg/L													
Influent	69	88	74	75	69	60	58	48	60	58	68	--	66
Effluent	14	16	15	14	11	9	9	10	13	15	15	--	13
TSS, mg/L													
Influent	42	65	52	58	51	44	48	47	53	61	58	--	53
Effluent	12	9	8	26	8	6	6	10	13	13	11	--	11

* Data represent average concentrations.

Table 12. Water quality data for the Lewistown WWTP discharge and Big Spring Creek, 1983 and 1987.

Sampling Location and Date	Flow cfs	Temperature °C	Lab pH	Turbidity ntu	TSS mg/L	NH_3 mg/L-N	NO_2+NO_3 mg/L-N	TIN mg/L-N	Ortho-P mg/L	Total-P mg/L	Specific Conductance umhos at 25°C
Big Spring Creek upstream of discharge (SC01)											
March 1983	165.8	7.0	8.35	4.0	9.2	<0.01	0.40	0.41	0.007	0.02	562
April 1983	167.3	5.0	8.20	2.5	12.2	0.03	0.36	0.39	0.009	0.01	559
July 1983	132.3	15.5	8.31	2.5	6.9	0.01	0.21	0.22	0.014	0.01	540
August 1983	122.5	12.0	8.16	3.5	11.0	<0.01	0.24	0.25	0.004	0.01	510
October 1983	170.5	8.0	8.34	4.7	4.6	<0.01	0.25	0.26	0.120	0.14	526
November 1983	134.4	7.0	8.19	2.9	4.2	<0.01	0.25	0.26	0.003	0.01	518
March 1987	142.8	10.0	8.16	5.0	10.4	<0.01	0.32	0.33	0.007	0.014	555
April 1987	143.4	13.9	----	---	----	<0.01	0.24	0.25	0.006	0.011	---
August 1987	107.8	14.4	----	0.8	2.3	0.01	0.22	0.23	0.003	0.007	538
October 1987	130.3	----	----	0.8	3.3	0.08	0.25	0.33	<.001	0.008	527
Lewistown WWTP discharge (SC02)											
March 1983	4.70	9.0	7.63	8.5	18.4	5.3	0.87	6.17	1.90	3.30	908
April 1983	4.62	8.0	7.49	11	30.0	4.5	0.80	5.30	1.50	2.80	942
July 1983	4.65	13.0	7.33	16	29.6	4.3	0.99	5.29	1.36	3.15	1031
August 1983	4.64	12.0	7.14	5.8	20.4	5.1	1.10	6.20	1.20	2.10	894
October 1983	4.65	12.0	7.29	23	34.3	4.3	1.00	5.30	1.39	3.05	810
November 1983	3.71	12.0	7.34	27	26.7	6.4	0.90	7.30	1.60	4.60	1045
March 1987	4.02	8.7	7.89	4.5	5.0	0.81	6.16	6.97	2.04	2.59	822
April 1987	3.70	11.4	----	----	----	0.66	8.85	9.51	2.06	2.43	---
August 1987	3.60	14.4	----	3.2	5.9	0.44	4.60	5.04	1.03	1.29	867
October 1987	3.54	----	----	4.0	7.3	0.46	6.25	6.71	1.55	1.92	860

Table 12. Continued

Sampling Location and Date	Flow cfs	Temperature °C	Lab pH	Turbidity ntu	TSS mg/L	NH_3 mg/L-N	NO_2+NO_3 mg/L	TIN mg/L-N	Ortho-P mg/L	Total-P mg/L	Specific Conductance umhos at 25°C
Big Spring Creek just downstream of discharge (SC03)											
March 1983	170.5	9.0	8.38	4.8	6.7	0.50	0.59	1.09	0.041	0.08	567
April 1983	171.9	9.0	7.34	2.8	6.5	0.12	0.35	0.47	0.038	0.08	565
July 1983	137.0	17.5	8.39	3.0	8.2	0.13	0.25	0.38	0.050	0.10	542
August 1983	127.2	13.0	7.94	2.5	8.6	0.22	0.27	0.49	0.062	0.10	552
October 1983	175.1	8.0	8.41	2.8	4.5	0.16	0.30	0.46	0.046	0.07	556
November 1983	138.1	7.0	8.40	4.5	4.5	0.09	0.25	0.34	0.031	0.07	532
March 1987	146.8	10.0	8.18	5.8	9.5	0.06	0.48	0.54	0.052	0.064	567
April 1987	147.1	15.9	----	----	----	<0.01	0.39	0.40	0.049	0.059	----
August 1987	111.4	17.2	----	0.9	3.0	0.03	0.37	0.40	0.058	0.085	542
October 1987	133.8	9.6	----	1.9	5.7	0.02	0.40	0.42	0.042	0.050	548
Big Spring Creek two miles downstream of discharge (SC04)											
March 1983	170.5	10.5	8.47	3.4	8.3	0.09	0.46	0.55	0.045	0.08	561
April 1983	171.9	10.0	8.42	2.1	8.2	0.07	0.41	0.48	0.042	0.07	564
July 1983	145.3	19.0	8.47	4.5	21.4	0.08	0.24	0.32	0.059	0.09	549
August 1983	129.3	17.0	8.22	2.7	9.8	0.13	0.33	0.46	0.078	0.11	545
October 1983	165.7	8.0	8.49	5.3	6.7	0.12	0.35	0.47	0.046	0.07	551
November 1983	137.2	7.0	8.53	6.0	8.6	0.06	0.28	0.34	0.042	0.07	540
March 1987	136.9	12.0	8.35	8.1	12.5	0.04	0.50	0.54	0.055	0.069	555
April 1987	----	16.4	----	----	----	<0.01	0.39	0.40	0.046	0.060	----
August 1987	102.2	17.5	----	1.2	4.2	0.03	0.34	0.37	0.054	0.068	544
October 1987	125.0	9.2	----	1.2	4.0	<0.01	0.43	0.44	0.053	0.061	552

Table 12. Continued

Sampling Location and Date	Flow cfs	Temperature °C	Lab pH	Turbidity ntu	TSS mg/L	NH_3 mg/L-N	NO_2+NO_3 mg/L	TIN mg/L-N	Ortho-P mg/L	Total-P mg/L	Specific Conductance umhos at 25°C
Big Spring Creek southeast of Hanover (SC05)											
March 1983	185.9	11.0	8.58	4.5	11.6	0.03	0.60	0.63	0.052	0.09	570
April 1983	190.8	12.0	8.52	4.3	11.3	0.04	0.50	0.54	0.045	0.09	564
July 1983	145.0	19.5	8.63	3.0	10.5	0.05	0.26	0.31	0.067	0.08	565
August 1983	127.5	19.0	8.53	2.4	8.3	0.04	0.31	0.35	0.050	0.06	569
October 1983	170.2	9.0	8.49	4.3	7.9	0.02	0.42	0.44	0.045	0.06	552
November 1983	133.4	6.0	8.49	5.9	11.0	0.01	0.41	0.42	0.039	0.08	529
March 1987	162.6	12.0	8.44	8.9	16.7	0.06	0.51	0.57	0.050	0.061	559
April 1987	----	16.8	----	----	----	<0.01	0.34	0.35	0.038	0.051	---
August 1987	114.2	17.9	----	1.2	3.3	0.02	0.25	0.27	0.043	0.054	583
October 1987	138.6	8.3	----	1.7	5.3	0.01	0.43	0.44	0.038	0.047	563

Table 13. Average values for selected water quality variables for the Lewistown WWTP discharge and Big Spring Creek, 1983 and 1987.

Sampling Location and Year	Flow cfs	Turbidity ntu	TSS mg/L	NH_3 mg/L-N	NO_2+NO_3 mg/L-N	TIN mg/L-N	Ortho-P mg/L	Total-P mg/L	Specific Conductance umhos at 25°C
SC01 1983	148.8	3.4	8.0	0.01	0.28	0.30	0.008	0.012	536
1987	131.1	2.2	5.3	0.02	0.26	0.29	0.004	0.010	540
% change	-12	-35	-34	+100	-7	-3	-50	-17	+1
SC02 1983	4.49	15.2	26.6	5.0	0.94	5.94	1.49	3.17	938
1987	3.71	3.9	6.1	0.59	6.46	7.05	1.67	2.06	850
% change	-17	-74	-77	-88	+587	+19	+11	-35	-9
SC03 1983	153.3	3.4	6.5	0.20	0.33	0.53	0.045	0.083	552
1987	134.8	2.9	6.1	0.03	0.41	0.44	0.050	0.064	552
% change	-12	-15	-6	-85	+24	-17	+11	-23	NC
SC04 1983	153.3	4.0	10.5	0.09	0.34	0.43	0.052	0.082	552
1987	121.4	3.5	6.9	0.02	0.41	0.43	0.052	0.064	550
% change	-21	-12	-34	-78	+21	NC	NC	-22	NC
SC05 1983	158.8	4.1	10.1	0.03	0.42	0.45	0.050	0.077	558
1987	138.5	3.9	8.4	0.02	0.38	0.40	0.042	0.053	568
% change	-13	-5	-17	-33	-9	-11	-16	-31	+2

mg/l in 1987. The average nitrate-nitrite concentration increased almost six-fold, a result of ammonia nitrification. Orthophosphorous increased slightly, while total phosphorous decreased slightly.

Water quality in Big Spring Creek at SC01 was very similar both years. Concentrations of most variables changed less than 50% from 1983 averages. However, ammonia increased 100% and orthophosphorous decreased 50% in 1987.

Water quality downstream of the WWTP was strongly influenced by the quality of the discharge. The clearest improvement occurred at SC03. Changes in TSS and nutrient concentrations coincided with changes in the discharge. The ammonia concentration decreased the most (85%); nitrate-nitrite increased the most (24%). Water quality at SC04 also improved, although the change in most pollutant concentrations was smaller than at SC03. AT SC05, all pollutants exhibited a decrease in average concentration after upgrading, including nitrate-nitrite and orthophosphorous, which had increased at SC03 and SC04 (Table 13) and in the discharge.

6.3.2 Benthic Macroinvertebrates

Three modified Hess samples and one traveling kick sample were collected at each stream site each season. Hess samples which were collected in 1983 were sorted and enumerated to the ordinal level only. All other samples were sorted and enumerated to genus or species.

Data from the kick samples were used in the integrated analysis of community-level parameters for comparing before and after conditions. These same parameters were calculated for the 1987 Hess samples and were analyzed by a two-way Analysis of Variance for significant differences by location or season. A Newman-Keul's test was used to compare each pair of factors within that variable.

Based on the 1983 data, slight degradation of the aquatic environment was discernible at each station below the WWTP (Table 14). With a single exception, cumulative scores were

Table 14. Mean values of parameters characterizing macroinvertebrate assemblages in Big Spring Creek above and below the Lewistown WWTP during 1983 and 1987 (three kick samples per station).

PARAMETER	STATION			
	SC01	SC03	SC04	SC05
Abundance				
1983	2,027	2,879	2,657	2,137
1987	2,713	2,562	4,360	2,665
Taxa richness				
1983	35	36	32	27
1987	29	31	27	27
Shannon diversity				
1983	3.37	2.96	2.96	2.76
1987	3.52	3.45	3.06	3.51
Biotic index (0-10)				
1983	4.02	5.14	4.75	4.50
1987	5.22	5.36	4.91	4.90
EPT richness				
1983	16	14	13	12
1987	9	10	10	10
EPT-Chironomidae ratio				
1983	10.9	4.3	13.7	10.4
1987	1.61	0.94	2.68	3.26
Scraper-filterer ratio				
1983	0.25	0.41	0.17	0.31
1987	0.63	0.52	0.69	0.73
PCS index *				
1983	---	55	47	50
1987	---	46	33	43

* Percent community similarity (X100) using station SC01 as the basis for comparison.

in the slightly impaired category (Table 15). The October score for station SC03 was slightly lower (25), falling between the slightly and moderately impaired ranges. Mean scores for stations SC03, SC04 and SC05 were 31, 35 and 35 respectively. Overall, EPT richness was the most sensitive parameter. A steady decline in the number of mayfly, stonefly and caddisfly species collected from SC01 to SC05 (Table 14) lowered scores for each downstream station. The percent community similarity and biotic indices also indicated slight impairment at each downstream site. The EPT to Chironomidae ratio was depressed at SC03.

The 1987 data indicated improved conditions downstream of the WWTP when compared to the upstream control site (Table 16). Mean scores for the 1987 data were 40, 36, 43 at stations SC03, SC04 and SC05, respectively. For each date tested during 1987, station SC04 was rated as slightly impaired while stations SC03 and SC05 were in the non-impaired category. Overall, scores for six of the eight parameters improved between 1983 and 1987. EPT richness and the biotic index accounted for 43% and 29%, respectively, of the net increase. Higher values assigned to the scraper to filterer ratio (functional feeding groups), Shannon diversity, taxa richness, and EPT to Chironomidae ratio also contributed to the higher cumulative scores.

However, there is evidence that degradation of the control site contributed to the higher scores during 1987. Taxa richness, biotic index, EPT richness and EPT to Chironomidae ratio indicated worsened conditions at SC01 during 1987 compared to 1983 (Table 14). Since these parameters accounted for 85% of the net improvement at downstream sites, the validity of the assessment for 1987 is questionable.

To test the hypothesis that environmental conditions had deteriorated between 1983 and 1987, the 1983 data were used as controls for assigning scores to each kick sample collected during 1987 (Table 17). Because laboratory methods differed between years (e.g. subsampling in 1987; the inclusion of tubificids and, apparently, more Chironomidae in the analyses for 1987) some parameters were biased. However, methods were

Table 15. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Lewistown WWTP during 1983 (one kick sample per season).

Station:	SC03			SC04			SC05		
Parameter	Apr.	Aug.	Oct.	Apr.	Aug.	Oct.	Apr.	Aug.	Oct.
Abundance	6	0	6	6	4	6	6	6	6
Taxa richness	6	6	5	6	6	6	6	4	4
Shannon diversity	4	6	4	4	2	6	4	0	6
Biotic index	4	2	2	4	3	4	3	4	6
EPT richness	4	6	0	2	4	1	4	2	0
EPT/C ratio	2	2	2	6	6	6	4	6	6
Scraper/filterer ratio	4	6	4	6	6	2	6	6	6
PCS index	6	4	2	4	2	2	4	2	3
Total score	36	32	25	38	33	33	37	30	37
Mean score		31			35			35	

Table 16. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Lewistown WWTP during 1987 (one kick sample per season).

Station:	SC03			SC04			SC05		
Parameter	Mar.	Aug.	Oct.	Mar.	Aug.	Oct.	Mar.	Aug.	Oct.
Abundance	6	6	4	4	6	4	6	4	6
Taxa richness	6	6	6	6	6	6	6	6	6
Shannon diversity	6	4	6	4	0	6	4	4	6
Biotic index	6	6	6	4	6	6	6	6	6
EPT richness	2	6	6	6	6	6	6	6	6
EPT/C ratio	4	2	4	6	6	4	6	6	6
Scraper/filterer ratio	6	6	6	4	2	6	6	6	6
PCS index	4	4	2	4	0	0	4	2	2
Total score	40	40	40	38	32	38	44	40	44
Mean score		40			36			43	

Table 17. Bioassessment scores for stations on Big Spring Creek above and below the Lewistown WWTP during 1987 using 1983 data as controls (one kick sample at each station per season).

Station:	SC01			SC03			SC04			SC05		
	Mar.	Aug.	Oct.	Mar.	Aug.	Oct.	Mar.	Aug.	Oct.	Mar.	Aug.	Oct.
Abundance	4	6	6	6	2	4	2	6	4	4	2	4
Taxa richness	6	6	4	6	4	6	4	6	6	6	6	6
Shannon diversity	6	6	6	6	6	6	6	6	6	6	6	6
Biotic index	1	4	3	2	6	6	4	6	6	4	4	6
EPT richness	0	0	0	0	4	4	2	4	6	0	4	6
EPT/C ratio	0	4	6	0	2	6	0	6	0	0	6	2
Scraper/filterer ratio	6	6	6	6	6	6	4	6	6	6	6	6
PSC index	3	2	2	2	4	0	4	2	2	4	2	6
Total score	26	34	33	28	34	38	26	42	36	30	36	42
Mean score		31			33			35			36	

consistent for each year and these biases should have been the same at each station. Therefore, the mean cumulative score for each station should reflect the degree of degradation between years, with lower scores indicating relatively more impact than higher scores. The mean score at SC01 (31) was lower than at progressive downstream stations by two, four and five points, respectively.

If this analysis is valid and if impacts were additive, the influence of control site degradation (reduced standards for comparison) on scores at each station between 1983 and 1987 can be quantified. Immediately below the WWTP effluent (SC03), the mean score increased from 31 during 1983 to 40 during 1987, so approximately 20% (2/9ths) of this apparent improvement resulted from degradation at the control site. Thus, nearly 80% of the increased score was attributable to improved water quality. Further downstream, improved environmental conditions were either not detected (SC04) or were primarily attributable (approximately 60% at SC05) to reduced standards of comparison.

Statistical analysis of Hess samples collected in 1987 failed to provide a clear pattern of differences among stations (Table 18). No significant differences ($p = 0.05$) were detected for mean Shannon diversity or EPT richness among stations. The scraper to filterer and EPT to Chironomidae ratios were significantly higher at SC05 than at other stations. These differences were due to fewer midges and more Helicopsyche sp. (a caddisfly scraper) at the downstream station and probably indicate more stable substrate as well as reduced organic pollution. At station SC04, total macroinvertebrate abundance was significantly higher while the ratio of insects to tubificids was significantly lower than at other stations. These results indicate that organic enrichment from the WWTP effluent had its greatest impact on benthic invertebrates at this site. Stoneflies and mayflies were also more abundant at this site, suggesting the primary effect of the effluent at SC04 was to

Table 18. Synopsis of statistical analyses (ANOVA and Newman-Keuls tests) of selected parameters characterizing macroinvertebrate assemblages at stations above and below the Lewistown WWTP during 1987 (nine modified Hess samples per station)[1].

Parameter	Significant differences among locations
Abundance	SC01, SC03, SC05 < SC04
Taxa richness	SC05 < SC03
Shannon diversity	no significant differences
Biotic index	SC01 < SC03, SC04, SC05
EPT richness	no significant differences
EPT-Chironomidae ratio	SC01, SC03, SC04 < SC05
Scraper-filterer ratio	SC01, SC03, SC04 < SC05
Insect-Tubificidae ratio	SC01, SC03, SC05 > SC04

[1] The March, 1987 Hess sample #1 from HS04 was destroyed during transport. The pooled (when appropriate) or mean parameter values of the remaining replicates were substituted for this missing value for statistical analyses.

enhance the food supply. The preponderance of tubificids and chironomids at SC04 was partially attributable to the finer substrate in this stream reach.

The biotic index provided a reliable measure of organic enrichment attributable to the WWTP. The mean biotic index value at SC01 (4.04) was significantly lower than at the downstream stations and, based on Hilsenhoff's (1987) scale for evaluation, was indicative of very good water quality with possible slight organic pollution. Mean values at SC03, SC04 and SC05 were 5.11, 5.96 and 5.06, respectively. Values between 4.51 and 5.50 indicate good water quality with some organic pollution while values between 5.51 and 6.50 typify fair water quality and fairly significant organic pollution (Hilsenhoff 1987).

Quantitative comparisons of species abundance between years were impeded by differences in laboratory processing and taxonomy. Organisms in the 1983 Hess samples were not identified below order, leaving the unreplicated kick samples as the only source of data for discrete taxa from both years. Discrepencies between these data sets further complicated efforts to interpret the data. Tubificidae (Oligochaeta), which during 1987 comprised one, twenty-two, fifteen and five percent of the fauna in kick samples at stations SC01, SC03, SC04 and SC05, respectively, were not included in the 1983 data. Therefore, tubificids were excluded when calculating the relative abundances in Table 19. For most numerically dominant taxa, site specific changes in mean relative abundance between 1983 and 1987 were within the range of variability normally expected. The seven-fold increase in the relative abundance of Physa sp. at station SC01 was an exception. However, kick samples may not have provided a reliable measure of the snails' relative abundance. While Physa sp. densities increased at SC01 between 1983 and 1987, they were relatively less abundant in Hess samples (three percent) than in kick samples (23%).

Areawide differences in the abundance of some species were more distinct (Table 19) and were not contradicted by the

Table 19. Percent relative abundance of numerically dominant macroinvertebrate taxa in traveling-kick samples from Big Spring Creek above and below the Lewistown WWTP during 1983 and 1987 (three samples per station each year combined).

	1983				1987			
Taxon	SC01	SC03	SC04	SC05	SC01	SC03	SC04	SC05
DIPTERA								
Orthocladius spp.	9%	11%	2%	2%	3%	3%	5%	2%
Polypedilum sp.	4%	11%	9%	5%	1%	5%	1%	1%
Antocha sp.	6%	2%	<1%	<1%	7%	1%	0%	<1%
EPHEMEROPTERA								
Baetis tricaudatus	6%	17%	21%	33%	12%	9%	20%	29%
Ephemerella infrequens/inermis	12%	17%	21%	7%	10%	7%	24%	13%
COLEOPTERA								
Optioservus quadrimaculatus	6%	1%	1%	5%	5%	2%	1%	5%
PLECOPTERA								
Isoperla quinquepunctata	10%	4%	5%	4%	<1%	<1%	4%	1%
TRICHOPTERA								
Hydropsyche occidentalis?	18%	5%	10%	23%	7%	2%	1%	13%
Brachycentrus americanus	14%	4%	3%	1%	4%	2%	2%	<1%
GASTROPODA								
Physa sp.	3%	11%	8%	2%	23%	8%	0%	2%
ISOPODA								
Asellus sp.	0%	<1%	5%	3%	1%	12%	9%	4%
TURBELLARIA	1%	2%	2%	4%	3%	17%	10%	6%

1987 Hess data. The relative abundance of one stonefly (Isoperla quequinpunctata) and two caddisflies (Hydropsyche occidentalis and Brachycentrus americanus) declined at all four stations in 1987 compared to 1983 while the converse was true for flatworms (Turbellaria) and an isopod (Asellus sp.). These changes may indicate habitat degradation throughout the study area. During both years, several abundant species appeared to be affected by the WWTP effluent. The abundance of the cranefly Antocha sp., and the riffle beetle Optioservus quadrimaculatus, were reduced downstream of the WWTP, while the midge Polypedilum sp. increased immediately downstream of the WWTP effluent.

Comparing species lists for the two years provided further evidence of environmental deterioration at SC01 between 1983 and 1987. Twelve species of stoneflies, mayflies and caddisflies (Alloperla sp., Claassinia sp., Cultus sp., Isoperla (possibly pinta), Baetis quilleri, Nixe simplicoides, Heptagenia soltari, Paraleptophlebia (probably heteronia), Symphitopsyche cockerelli, S. slossonae, Brachycentrus occidentalis, and Glossosoma sp.) present at SC01 in 1983 were not found in 1987 (either kick or Hess samples). All twelve species were rare during 1983 with only one or two individuals of most species being collected. Consequently, some species may have been missed due to subsampling. However, Cultus sp., Paraleptophlebia sp. and Glossosoma sp. were present at downstream stations during 1987 and only one species of caddisfly (Hydroptila sp.) was collected at SC01 in 1987 that was not found there in 1983. The loss of so many sensitive species must be considered evidence of increased environmental stress at the control site.

Data from Hess samples also suggested diminished environmental quality in 1987 relative to 1983. Mean macroinvertebrate densities declined by 41%, 65% and 60% at stations SC01, SC03, and SC05, respectively, between years (Table 20). At SC04, where the mean macroinvertebrate density increased three percent between 1983 and 1987, tubificids replaced caddisflies as the predominant benthic invertebrate. Caddisfly densities and relative abundances were greatly reduced at all

Table 20. The mean density (number per sample) and percent relative abundance (in parentheses) of macroinvertebrate orders in Big Spring Creek above and below the Lewistown WWTP during 1983 and 1987 (nine modified Hess samples per station each year).

	STATION							
TAXON	SC01		SC03		SC04		SC05	
Plecoptera								
1983	52	(3)	61	(3)	24	(2)	14	(1)
1987	8	(1)	2	(<1)	59	(4)	21	(4)
Trichoptera								
1983	902	(57)	522	(24)	704	(46)	883	(58)
1987	353	(38)	142	(19)	159	(10)	196	(32)
Ephemeroptera								
1983	199	(13)	523	(24)	214	(14)	350	(23)
1987	126	(13)	80	(10)	174	(11)	139	(23)
Coleoptera								
1983	40	(3)	13	(1)	13	(1)	53	(4)
1987	100	(11)	36	(5)	10	(1)	36	(6)
Diptera								
1983	358	(23)	831	(38)	253	(17)	144	(10)
1987	295	(32)	236	(31)	359	(23)	71	(12)
Isopoda								
1983	0		1	(<1)	149	(10)	16	(1)
1987	1	(<1)	48	(6)	143	(9)	96	(16)
Gastropoda								
1983	5	(<1)	181	(8)	34	(2)	10	(1)
1987	27	(3)	29	(4)	6	(<1)	1	(<1)
Other								
1983	13	(1)	36	(2)	50	(3)	43	(3)
1987	24	(3)	187	(25)	661	(42)	48	(8)
Total								
1983	1570		2166		1516		1514	
1987	934		760		1571		608	

stations during 1987. Mayfly densities were similarly reduced during 1987 and stoneflies were less abundant at SC01 and SC03 in 1987. Apparent changes in relative abundance should be evaluated cautiously because Tubificidae were included in the 1987 data (McGuire 1988b).

6.3.3 Chlorophyll a Production

The rate of growth of algal biomass on artificial substrates was estimated by measuring the rate of production of chlorophyll a. Chlorophyll a generally comprises one to two percent of algal biomass. Estimates of algal biomass production were derived by multiplying the chlorophyll a accrual rate by a constant of 67, which represents 1.5% of algal biomass as chlorophyll a (Table 21).

The greatest, and only significant (p=.05) difference in chlorophyll a accrual between 1983 and 1987 occurred at SC03, where the average accrual rate and estimated biomass production were almost four times greater in 1987. Average values for both variables were slightly higher at SC01, and lower at SC04 and SC05, in 1987, but not significantly so.

6.4 Discussion

Concentrations of BOD, TSS, and ammonia in the effluent decreased significantly after upgrading. Nitrate-nitrite concentrations increased almost six-fold, a result of ammonia nitrification. Concentrations of orthophosphorous and total phosphorous were only slightly changed.

Water quality in Big Spring Creek reflected the improvement in the quality of the discharge (Table 13). At SC03, water quality was strongly affected by the improvement in the quality of the discharge. At SC04 and SC05, the WWTP discharge was still a major determinant of water quality, in that nutrient concentrations had not decreased to background levels. However, nutrient concentrations at these stations in 1987 were usually slightly less than or unchanged from concentrations in 1983.

Table 21. Chlorophyll a accrual and estimated biomass production, Big Spring Creek, 1983 and 1987.

Sampling Location and Year	Chlorophyll a accrual, $mg/m^2/day$ Replicates				Estimated biomass production, $mg/m^2/day$ Replicates			
	# 1	# 2	# 3	Avg.	# 1	# 2	# 3	Avg.
SC01								
1983	0.335	0.478	0.491	0.435	22.46	32.03	32.90	29.13
1987	0.234	0.615	0.742	0.530	15.68	41.20	49.71	35.53
SC03								
1983	0.692	0.744	1.775	1.070	46.36	49.85	118.92	71.71
1987	3.128	3.905	4.589	3.874	209.58	261.64	307.46	259.56
SC04								
1983	0.773	1.134	1.920	1.276	51.79	75.98	128.64	85.47
1987	0.713	0.764	1.132	0.870	47.77	51.19	75.84	58.27
SC05								
1983	0.452	0.550	0.625	0.542	30.28	36.85	41.88	36.34
1987	0.229	0.306	0.755	0.430	15.34	20.50	50.58	28.81

Improvement in instream water quality could not be so easily and incontrovertibly documented by macroinvertebrate populations. An assessment of the affects of improved water quality was complicated by altered conditions at the control site.

Prior to upgrading, the WWTP effluent had a slight but easily identifiable impact on the biota of the receiving stream. Some sensitive species experienced localized reductions in abundance near the effluent outfall (e.g. Optioservus quadrimaculatus and Hydropsyche occidentalis) while others were less abundant at all downstream stations (e.g. Antocha sp. and Brachycentrus americanus). Tolerant species were more abundant immediately below the discharge (e.g. Polypedilum sp.) or throughout the downstream study area (e.g. Baetis tricaudatus and Ephemerella inermis/infrequens). In addition, many community-level indices (total macroinvertebrate density, Shannon diversity, biotic index and EPT to Chironomidae ratio) exhibited classic responses to mild organic pollution at the station immediately downstream of the WWTP's discharge. Further downstream, the slight impairment detected was, at least partially, a consequence of poor habitat.

During 1987, the abundance and taxa richness of aquatic insects was reduced at all stations in Big Spring Creek relative to 1983, including SC01. Insect densities were reduced by 40% to 60% throughout the study area. The most dramatic impact was upstream of the WWTP effluent, where twelve species of stoneflies, mayflies or caddisflies present during 1983 were not found in 1987. Habitat requirements of the species most affected indicated sediment deposition as the probable cause of the significant environmental deterioration reported for 1987. The severity of this impact may have been augmented by the lack of periodic flushing provided by high stream flows and the precipitation of large quantities of calcite (calcium carbonate). Sediment deposition and calcite precipitation appeared to be more severe in 1987 than in 1983. Calcite precipitation appeared to be greatest at SC01, and less noticeable or not present below the

outfall. Sediment deposition and substrate shifting and scouring was evident throughout the study reach.

The integrated bioassessment, although compromised by lower standards of comparison resulting from degradation at the control site, detected no impairment at two of the three downstream stations. The improved sewage treatment did appear to reduce environmental stress in downstream reaches, particularly near the effluent outfall (SC03). The biotic index indicated some organic pollution downstream of the WWTP during 1987. The effects of organic enrichment were most pronounced at station SC04 approximately two miles downstream. For most numerically dominant taxa, abundance and distribution patterns were similar between 1983 and 1987, although differences among stations were generally diminished. A slight impact attributable to organic enrichment from the WWTP was present during 1987; however, this impact was largely overwhelmed by deterioration of the physical environment in Big Spring Creek (McGuire 1988b).

In 1987, chlorophyll a accrual just downstream of the outfall was almost four times higher than before upgrading. Average accrual rates at SC04 and SC05 were slightly lower, though not significantly so. The increase in chlorophyll a accrual and estimated biomass production at SC03 may have been due to higher concentrations of bio-available nutrients in the discharge, especially during the testing period (March and April). Ammonia nitrification increased nitrate-nitrite concentrations in the effluent almost ninefold after upgrading. Orthophosphorous increased slightly. This increase was barely detectable at SC03 possibly because of rapid nutrient assimilation by algae and macrophyte growth in this reach. The relatively constant nutrient concentrations at SC03, SC04, and SC05 may indicate that the assimilative capacity of the stream had been exceeded or reached.

7. BITTERROOT RIVER STUDY

7.1 Overview

Hamilton's WWTP, which serves a town of population 2700 located in the Bitterroot River valley about 50 miles south of Missoula, was built in the 1950's. Excessive infiltration and hydraulic overloading necessitated reconstruction of the WWTP to meet a fourfold increase in influent volume that occurs during the summer months.

The new WWTP is an oxidation type activated sludge facility. Two concentric oxidation ditches and three secondary clarifiers provide the treatment capacity to handle peak summer flows. As a result of summer irrigation, infiltration increases influent flows from 0.7 mgd in the winter to 2.5 mgd in the summer. After final clarification, the effluent passes through a chlorine contact basin before discharging to the Bitterroot River. Dechlorination of the effluent by sulphur dioxide is practiced in the summer.

The Bitterroot River is a relatively large stream that generally provides a dilution ratio of at least 100:1 for Hamilton's wastewater discharge. During spring runoff, dilution may reach 1000:1. Due to the linear nature of the stream reach just downstream of the WWTP outfall, the effluent plume hugs the right bank for upwards of one mile before the channel configuration promotes significant lateral mixing.

The river's headwaters lay in the Bitterroot Range south of Hamilton. The river flows northward to Missoula where it joins with the Clark Fork River. The Bitterroot River is classified B-1. It's waters are suitable for potable, recreational, agricultural, and industrial uses, and for growth and propagation of cold water aquatic life. The river and valley are known for their scenic and recreational opportunities with hunting, fishing, camping, and boating being very popular.

7.2 Sampling Locations and Description

Three monitoring stations were located on the Bitterroot River. The control (BR01) was located approximately

one-quarter mile upstream of the discharge (BR02). The station approximately one-half mile downstream of the discharge (BR03) was located within the effluent plume. Conditions at this location reflect the worst possible before upgrading, with the most potential for improvement after upgrading. The farthest downstream station (BR04) was approximately two miles below the discharge (Figure 3).

7.3 Results

7.3.1 Water Chemistry

Water quality data (Tables 22 and 23) indicate that turbidity, TSS, and ammonia were reduced over 90% after upgrading. Orthophosphorous and total phosphorous were approximately half their concentrations before upgrading. Nitrate-nitrite concentrations, which were barely detectable prior to upgrading, increased almost two hundred times. TIN increased almost fifty percent, possibly because of more complete treatment of organic material previously discharged as TSS.

Loadings of TSS, ammonia, orthophosphorous, and total phosphorous to the Bitterroot River (Table 24) decreased significantly. Nitrate-nitrite loading increased almost seventy-five fold. Increases in TIN and decreases in phosphorous and TSS loadings indicate more complete nitrification and removal of organic material.

Limited water quality data, and the lack of flow data for the Bitterroot River, precluded a detailed analysis of instream water quality conditions. Generally, water quality at BR03, which was located in the plume of the effluent, reflected the quality of the discharge. Ammonia, orthophosphorus, and total phosphorous decreased commensurately with their effluent concentrations. Nitrate-nitrite concentrations increased sixfold. TSS and turbidity were influenced more by water quality upstream of the discharge than by the improvement in the quality of the discharge.

Nutrient concentrations, excepting ortho-phosphorous, were slightly higher in 1986 than 1983 at BR04. Turbidity and

Figure 3. Sampling locations for the Bitterroot River before-and-after study.

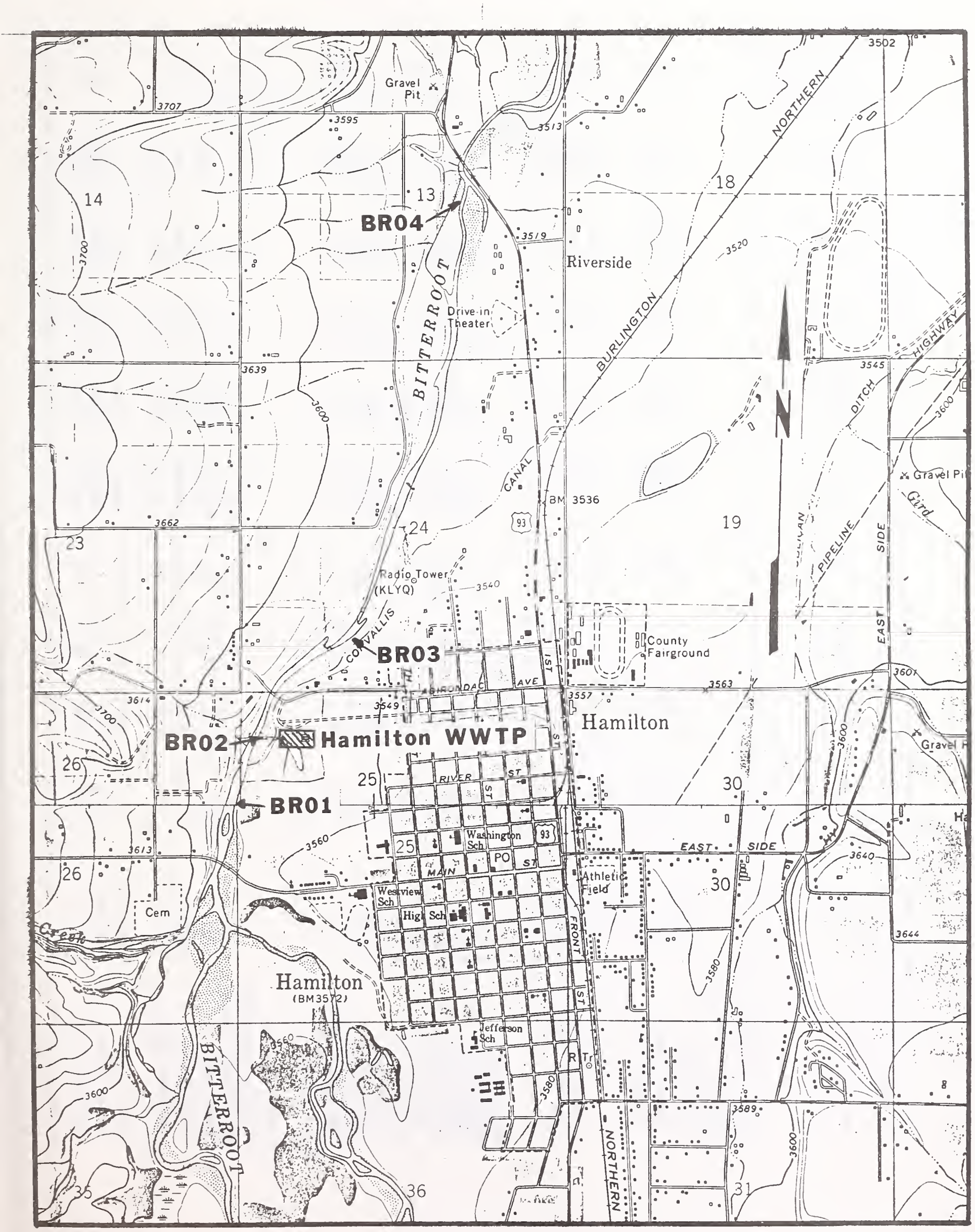

Table 22. Water quality data for the Hamilton WWTP discharge and the Bitterroot River, 1983 and 1986.

Sampling Location And Date	Flow* cfs	Temp. °C	Field pH	Turbidity ntu	TSS mg/L	NH_3 mg/L-N	NO_2+NO_3 mg/L-N	TIN mg/L	Ortho-P mg/L	Total-P mg/L	Specific Conductance umhos at 25°C
Bitterroot River upstream of Hamilton WWTP (BR01)											
March 1983	600 (E)	4.5	7.70	2.5	9.2	<0.01	0.02	0.02	0.006	0.01	77
August 1983	534	21.0	8.50	1.5	2.8	<0.01	0.01	0.01	0.019	0.03	94
November 1983	500 (E)	4.5	6.80	1.7	1.7	0.01	<0.01	0.01	0.003	0.01	76
April 1986	1200 (E)	6.5	6.55	11.5	39.4	<0.01	<0.01	<0.01	0.019	0.045	42
August 1986	350 (E)	18.4	7.10	1.2	--	<0.01	0.01	0.01	0.004	0.009	83
November 1986	300 (E)	3.8	7.15	0.5	1.3	<0.01	<0.01	<0.01	<0.001	0.005	98
Hamilton WWTP discharge (BR02)											
March 1983	0.84	11.0	6.65	42.	60.5	13.0	0.02	13.02	8.70	10.0	776
August 1983	2.98	18.0	6.90	14.	27.2	2.8	0.18	2.98	2.90	4.2	418
November 1983	0.68	10.0	6.00	43.	61.2	11.5	<0.01	11.5	7.89	13.4	744
April 1986	0.67	14.4	7.95	1.5	1.9	0.09	19.3	19.39	5.42	5.84	638
August 1986	3.34	16.7	7.30	4.0	--	0.41	3.50	3.91	1.27	1.68	348
November 1986	1.20	10.6	7.40	1.2	2.7	0.06	16.6	16.66	4.94	5.20	598
Bitterroot River 0.5 miles downstream of discharge (BR03)											
March 1983	600 (E)	4.5	7.75	3.0	5.3	0.07	0.02	0.09	0.060	0.08	82
August 1983	537	21.0	7.80	1.8	3.5	0.04	0.02	0.06	0.078	0.09	92
November 1983	500 (E)	5.0	6.95	1.8	2.4	0.07	<0.01	0.07	0.054	0.06	83
April 1986	1200 (E)	7.1	6.95	11.5	32.0	<0.01	0.01	0.01	0.023	0.047	51
August 1986	350 (E)	21.8	7.45	1.0	--	0.01	0.10	0.11	0.042	0.045	92
November 1986	300 (E)	4.5	7.80	0.5	1.5	<0.01	0.08	0.08	0.029	0.029	91

Table 22. Continued.

Sampling Location And Date	Flow* cfs	Temp. °C	Field pH	Turbidity ntu	TSS mg/L	NH_3 mg/L-N	NO_2+NO_3 mg/L-N	TIN mg/L	Ortho-P mg/L	Total-P mg/L	Specific Conductance umhos at 25°C
Bitterroot River at Highway 93 (BR04)											
March 1983	600 (E)	4.5	7.60	2.7	4.2	<0.01	0.02	0.02	0.014	0.02	77
August 1983	537	22.0	8.40	1.5	3.2	<0.01	0.01	0.01	0.034	0.04	84
November 1983	500 (E)	5.0	7.65	2.5	1.6	<0.01	<0.01	<0.01	0.010	0.01	74
April 1986	1500 (E)	7.2	7.00	11.5	30.7	<0.01	0.01	0.01	0.017	0.044	37
August 1986	375 (E)	22.1	7.80	1.0	--	0.01	0.05	0.06	0.019	0.024	92
November 1986	350 (E)	5.1	8.00	0.5	1.6	0.04	0.02	0.06	0.009	0.013	92

* (E) Estimated flows based upon visual observation.

Table 23. Average values of selected water quality variables for the Hamilton WWTP discharge and the Bitterroot River, 1983 and 1986.

Sampling Location and Year		Turbidity ntu	TSS mg/L	NH_3 mg/L-N	$NO_2 + NO_3$ mg/L-N	TIN mg/L-N	ORTHO-P mg/L	Total P mg/L	Specific Conductance umhos at 25°C
BR01	1983	1.9	4.6	<0.01	0.01	<0.01	0.009	0.02	82
	1986	4.4	29.3	<0.01	<0.01	<0.01	0.008	0.02	74
	% change	+132	+341	NC	-50	NC	-11	NC	-10
BR02	1983	33.	49.6	9.10	0.07	9.17	6.50	9.20	646
	1986	2.2	2.3	0.19	13.10	13.29	3.88	4.24	528
	% change	-93	-95	-98	+18600	+45.	-40	-54	-18
BR03	1983	2.2	3.7	0.06	0.01	0.07	0.064	0.080	86
	1986	4.3	16.8	<0.01	0.06	0.06	0.031	0.040	78
	% change	+95	+354	-92	+500	-14	-52	-50	-9
BR04	1983	2.2	3.0	<0.01	0.01	0.01	0.019	0.020	78
	1986	4.3	16.1	0.03	0.03	0.06	0.015	0.027	74
	% change	+95	+437	+500	+200	+500	-21	+35	-5

Table 24. TSS and nutrient loading (pounds per day) to the Bitterroot River from the Hamilton WWTP, 1983 and 1986.[1]

DATE	TSS	NH_3-N	NO_2+NO_3-N	TIN	O-PO_4	T-P
March 1983	274	58.9	0.1	59.0	39.4	45.3
August 1983	437	45.0	2.9	47.9	46.6	67.5
November 1983	224	42.1	0.2	42.3	28.9	49.1
Average	312	48.7	1.0	49.7	38.3	54.0
April 1986	7	0.3	69.7	70.0	19.6	21.1
August 1986	--	7.4	63.0	70.4	22.9	30.2
November 1986	17	0.4	107.4	107.8	31.9	33.6
Average	12	2.7	80.0	82.7	24.8	28.3
Percent Change	-96	-94	+7520	+66	-35	-85

[1] Loadings were calculated using instantaneous flows measured at the time of sampling.

TSS, as at BR03, were most affected by ambient water quality upstream of the discharge.

7.3.2 Benthic Macroinvertebrates

In 1983, one composite kick sample was collected per site each season. In 1986, three unit-effort kick samples were collected per site each season.

During 1983, the mean values of four community-level parameters indicated differences in macroinvertebrate assemblages above and below the WWTP outfall (Table 25). Some of these indices (biotic index, EPT to Chironomidae ratio and PCS index) returned to ambient levels further downstream (BR04). Based on Hilsenhoff's (1987) evaluation of water quality using biotic index values, stations BR01 and BR04 had excellent water quality with no apparent organic pollution while BR03 had very good water quality with possible slight organic pollution. The relative increase in the abundance of filter feeders (expressed as the ratio of scrapers to filter feeders) suggested that increased nutrient loading changed the foodbase downstream from the WWTP.

Population data for numerically dominant taxa also indicated an impact attributable to the WWTP effluent during 1983 (Table 26). The relative abundance of Lepidostoma sp., the most numerous macroinvertebrate in the study area, was severely reduced at BR03 compared with the other stations. Conversely, Polypedilum sp., a species more tolerant of organic enrichment, was a minor component of the macroinvertebrate assemblage at BR01 and BR04, but was the second most abundant species at BR03 where it comprised 13% of the fauna. The virtual elimination of Lepidostoma sp. at BR03 may have been due to toxic conditions (probably episodes of high chloramines concentrations) near the effluent outfall. Lepidostoma may, therefore, be useful for detecting chlorine plus ammonia impacts in streams where it is abundant.

Following the WWTP upgrade, differences in the relative abundances of numerically dominant taxa were not evident (Table 26) although values of community-level parameters varied among

Table 25. Mean values of parameters characterizing macroinvertebrate assemblages above and below the Hamilton WWTP during 1983 and 1986 (three samples per station in 1983 and nine samples per station in 1986).

	1983			1986		
PARAMETER Station:	BR01	BR03	BR04	BR01	BR03	BR04
Abundance	3,300	2,500	3,600	2,800	2,900	4,800
Taxa richness	48	47	44	58	51	49
Shannon diversity	3.4	3.5	3.1	3.7	3.7	3.4
Biotic index (0-10)	2.9	4.1	2.7	3.1	3.4	3.6
EPT richness	28	27	27	30	28	23
EPT/C ratio	21	10	21	8	4	4
Scraper/filterer ratio	2.1	0.8	0.6	3.9	1.2	1.3
PCS index *	---	55	65	---	71	69

* Percent community similarity (X100) using station BR01 as the basis for comparison.

Table 26. The mean percent relative abundance of the numerically dominant macroinvertebrate taxa above and below the Hamilton WWTP during 1983 and 1986 (three samples per station in 1983 and nine samples per station in 1986) and for all samples combined.

		1983			1986		
Taxon	Overall	BR01	BR03	BR04	BR01	BR03	BR04
Lepidostoma sp.	29%	32%	2%	44%	31%	37%	32%
Ephemerella infrequens	15%	21%	25%	18%	8%	6%	15%
Optioservus spp.	7%	10%	10%	7%	7%	2%	5%
Hydropsyche slossonae ?	4%	3%	6%	4%	5%	2%	4%
Brachycentrus occidentalis	4%	4%	3%	12%	1%	1%	1%
Polypedilum sp.	3%	<1%	13%	2%	1%	2%	3%
Drunella flavilinea	3%	0%	0%	0%	4%	9%	4%
Hydroptila sp.	2%	<1%	0%	1%	7%	5%	2%
Baetis tricaudatus	2%	2%	6%	1%	1%	2%	1%

stations (Table 25). The two-way analysis of variance on replicate samples indicated significant differences ($p = 0.05$) among stations for five of the seven parameters while four parameters exhibited significant seasonal variation. The Newman-Keuls test identified significant differences among stations for only three parameters: total abundance, biotic index and EPT to Chironomidae ratio (Table 27). The multiple range test did not identify significant differences among stations for mean Shannon diversity or EPT richness values although the ANOVA found significant differences in both parameters ($p = 0.05$). The inconsistent statistical results were probably a consequence of skewed data distributions.

Using the 1983 data as a baseline, the 1983 and 1986 data for the control station were compared to determine their similarity and to test for upstream perturbations that influenced the study reach. Scores for the 1986 data ranged from 44 to 34 with a mean of 41. The spring and autumn values, as well as the overall mean, were in the non-impaired category which indicated the data sets were generally comparable. However, the cumulative score for the summer sample was in the slightly impaired range. The lower score appeared attributable to slight ambiguities in field and laboratory procedures rather than to altered environmental conditions. For instance, smaller and therefore more midges were apparently included in the 1986 data. While anomalies between data sets precluded more detailed comparisons between the 1983 and 1986 data, they did not bias the comparative analysis.

Based on the 1983 data, a slight impairment of the aquatic environment was discernable at both stations below the WWTP (Table 28). The impact was most evident at BR03 where, on each occasion, the cumulative score was 28, near the bottom of the slightly impaired range. Scores were more variable at BR04, ranging from 30 to 42. The November sample from BR04 received a non-impacted rating while the spring and summer scores were in the slightly impaired category.

Table 27. Synopsis of statistical analyses (Newman-Keuls test) of selected parameters characterizing macroinvertebrate assemblages at stations above and below the Hamilton WWTP during 1986.

Parameter	Location
Abundance	BR01 = BR03 < BR04
Taxa richness	BR01 = BR03 = BR04
Shannon diversity	BR01 = BR03 = BR04
Biotic index	BR01 < BR04
EPT richness	BR01 = BR03 = BR04
EPT/C ratio	BR01 > BR03 = BR04
Scraper/filterer ratio	BR01 = BR03 = BR04

Table 28. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Hamilton WWTP during 1983 (one sample per season).

Station:	BR03			BR04		
PARAMETER	Mar.	Aug.	Nov.	Mar.	Aug.	Nov.
Abundance	6	2	4	6	0	6
Taxa richness	6	6	4	6	6	6
Shannon diversity	6	6	6	6	4	4
Biotic index	0	2	0	4	6	6
EPT richness	4	6	2	6	6	6
EPT/C ratio	2	2	4	6	6	4
Scraper/filterer ratio	2	2	6	0	0	6
PCS index	2	2	2	4	2	4
Total score	28	28	28	38	30	42
Mean		28			37	

Following the WWTP upgrade, scores for BR03 were consistently higher (Table 29) though still in the slightly impaired category on two of the three dates sampled in 1986. With the mean score increasing from 28 in 1983 to 37 in 1986, environmental stresses appear to have been reduced near the WWTP outfall. At station BR04, approximately 2 miles downstream, the mean cumulative score decreased from 37 in 1983 to 31 in 1986. This decline, while not significant with regard to impact severity, was in accord with the slight increase in nutrient concentrations measured at the downstream station during 1986 compared to 1983. Thus, the upgraded treatment at the Hamilton WWTP appears to have reduced impacts near the outfall while shifting the impact associated with nutrient loading further downstream (McGuire 1988c).

7.4 Discussion

Water quality data clearly indicate that the WWTP upgrading improved the quality of the discharge. TSS was reduced over 90%. Phosphorous concentrations and loadings to the Bitterroot River also decreased. Inorganic nitrogen loading increased, probably because of more complete treatment of influent organic nitrogen. However, the ammonia nitrogen fraction decreased to less than 0.5 ppm because of more complete nitrification.

An improvement in instream water quality was best documented at BR03. As this station was located in the effluent plume, changes in nutrient concentrations were consistent with their increase or decrease in the WWTP effluent. Two miles below the discharge (BR04), average concentrations of all nutrients, except orthophosphorous, increased in 1986. This increase was especially perplexing because ammonia, TIN, and total phosphorous had decreased at BR03. However, nitrate-nitrite, orthophosphorous, and total phosphorous did exhibit a station-to-station decrease between BR03 and BR04. No satisfactory explanation could be developed to explain these results. One possibility is that a different benthic community became

Table 29. Scores assigned to diagnostic macroinvertebrate parameters at stations below the Hamilton WWTP during 1986 (three samples per season).

Station:	BR03			BR04		
PARAMETER	Apr.	Aug.	Nov.	Apr.	Aug.	Nov.
Abundance	4	6	6	0	4	6
Taxa richness	6	6	4	6	6	4
Shannon diversity	6	6	6	6	6	6
Biotic index	6	6	4	4	4	4
EPT richness	6	6	2	4	4	0
EPT/C ratio	4	6	2	2	2	4
Scraper/filterer ratio	4	0	6	2	2	4
PCS index	6	4	4	6	4	2
Total score	42	36	34	30	32	30
Mean		37			31	

established in response to changes in nitrogen and phosphorous concentrations, which resulted in different nutrient assimilation dynamics. The net effect, nonetheless, was a slightly more enriched environment at BR04 after upgrading than before.

Results of the integrated bioassessment of macroinvertebrate communities suggest that the upgraded treatment appears to have reduced impacts near the outfall while shifting the impact associated with nutrient loading further downstream. Impacts identified at BR03 in 1983 included a cumulative score near the bottom of the slightly impaired range, compared to a slightly impaired or non-impaired rating at BR04; a biotic index value indicative of very good water quality with possible slight organic pollution compared to excellent water quality with no apparent organic pollution at BR04; a severe localized reduction in the caddisfly Lepidostoma sp., possibly from chloramine toxicity; and a localized abundance of the midge Polypedilum sp., which is tolerant to organic pollution. A less distinct impact was detected at station BR04 in the spring and summer of 1983, where enhanced periphyton growth affected the community structure.

In 1986, cumulative scores were consistently higher at BR03 but lower at BR04, although both were slightly impaired. The lack of apparent differences in the relative abundances of numerically dominant taxa suggest that the impact at BR04 was relatively slight compared to the impact at BR03 in 1983. Increased scraper/filterer ratios suggest less effect from nutrient and organic loading.

In 1983, impacts below the WWTP discharge were most likely related to organic enrichment and chloramine or ammonia toxicity. In 1986, impacts associated with effluent toxicity were no longer detectable. Impacts associated with nutrients and organic enrichment, while slight both years, were more evident at BR04 in 1986. Overall, the Bitterroot River appears to be in excellent condition with macroinvertebrate assemblages indicative of aquatic environments with very good habitat and water quality.

8. CONCLUSIONS

In each before-and-after study, an improvement in the quality of the WWTP discharge attributable to upgrading could be readily documented. In all three cases, TSS loadings were reduced. Ammonia concentrations, often high enough to be potentially toxic, were reduced by nitrification. This resulted in much higher loadings of nitrate-nitrite nitrogen to the receiving streams.

Documenting improvement in the quality of the receiving streams was more difficult. In Hot Springs Creek, extremely variable streamflows and significant flow alterations and pollutant loadings from other sources masked the effects of the lagoon discharge. In Big Spring Creek, decreases in pollutant concentrations could be detected at three stations, and up to five miles, downstream of the discharge. Improvement was more subtle as downstream distance increased. In the Bitterroot River a significant improvement could be detected in the mixing zone, but two miles downstream nutrient concentrations may have actually increased after upgrading.

Analysis of macroinvertebrate samples detected, at best, only modest improvement attributable to the upgrading of sewage treatment facilities. Hot Springs Creek, before and after upgrading, was impaired by multiple environmental stresses, including habitat degradation and organic pollution related to natural biological and geological processes. Under a more normal flow regime results of the upgrading may be more apparent. Improved sewage treatment at Lewistown appeared to reduce environmental stress in downstream reaches; however, this improvement was largely overwhelmed by deterioration of the physical environment throughout the study reach. Impacts of the Hamilton WWTP on the Bitterroot River appeared to be slight both before and after upgrading. As a result of more complete nitrification after upgrading, impacts associated with nutrient enrichment were shifted downstream. Overall, the river was and continues to remain in excellent condition.

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